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DISSERTATION

Ignoring the Innocent

Non-combatants in Urban Operations and in Military Models and Simulations

Yuna Huh Wong

This document was submitted as a dissertation in March, 2006 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of James T. Quinlivan (Chair), Steven C. Bankes, Russell W. Glenn, and Randall Steeb.

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Preface

This dissertation is submitted to the Frederick S. Pardee RAND Graduate School (PRGS) in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Policy Analysis. It was funded by the Arroyo Center for Army Research at the RAND Corporation. Opinions expressed in this dissertation are those of the author and do not necessarily reflect those of PRGS, RAND, or any RAND sponsor.

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Abbreviations

Symbol	**Definition**
ABD	Agent-Based Distillation
ABM	Agent-Based Model/Modeling
ADAS	Air-deliverable Acoustic Sensor
AFB	Air Force Base (U.S.)
CA	Cellular Automata
CAS	Complex Adaptive System
CEP	Circular Error Probable
CNA	Center for Naval Analyses (U.S.)
CROCADILE	Conceptual Research Oriented Combat Agent Distillation Implemented in the Littoral Environment
DMSO	Defense Modeling and Simulation Office (U.S.)
DoD	Department of Defense (U.S.)
DoE	Department of Energy (U.S.)
DoT	Department of Transportation (U.S.)
DOTSE	Defence Operational Technology Support Establishment (Australia)
DSMAC	Digital Scene Matching Area Correlation
DSTL	Defence Science and Technology Laboratories (UK)
DSTO	Defence Science and Technology Organization (Australia)
DTA	Defence Technology Association (New Zealand)
EBM	Equation-Based Model/Modeling
EDM	Defence Science and Technology Laboratories (UK)
EINSTein	Defence Science and Technology Organization (Australia)
EPA	Environmental Protection Agency (U.S.)
FCS	Future Combat Systems
FOPEN	Foliage Penetration Radar
GHG	Greenhouse Gas
GPS	Global Positioning System

HE	High Explosive
HITL	Human in the Loop
HITM	Hierarchical Interactive Theater Model
ID	Infantry Division (U.S.)
IDP	Internally Displaced Person
IPB	Intelligence Preparation of the Battlefield
ISAAC	Irreducible Semi-autonomous Adaptive Combat
JCATS	Joint Conflict and Tactical Simulation
JDAM	Joint Direct Attack Munition
JSAF	Joint Semi-Automated Forces
JTF	Joint Task Force
LGB	Laser Guided Bomb
MANA	Map Aware Non-uniform Automata
MCCDC	Marine Corps Combat Development Command (U.S.)
MOE	Measure(s) of Effectiveness
MOOTW	Military Operations Other Than War
NASDAQ	National Assoc. of Security Dealers Automated Quotation
NATO	North Atlantic Treaty Organization
NGO	Non-Governmental Organization
NEO	Non-Combatant Evacuation Operation
OEF	Operation Enduring Freedom (2002 Afghanistan)
OIF	Operation Iraqi Freedom (2003–04 Iraq)
OODA	Observe-Orient-Decide-Act
PDF	Panamanian Defense Forces
PGM	Precision Guided Munition
P_k	Probability of Kill
PSI	Pounds per Square Inch
PSYOPS	Psychological Operations
ROE	Rules of Engagement
SAFORs	Semi-Automated Forces
SAR	Synthetic Aperture Radar
SOSO	Stability and Support Operations

SEM	Strategic Effects Model
SNA	Somali National Alliance
SSC	Small-scale Contingency
TLE	Target Location Error
UAV	Unmanned Aerial Vehicle
UNOSOM II	United Nations Operations in Somalia II
USA	United States Army
USAF	United States Air Force
USECT	Understand, Shape, Engage, Consolidate, and Transition
USMC	United States Marine Corps
USSOUTHCOM	United States Southern Command
VBSEM	Value-Based Strategic Effects Model
WMD	Weapons of Mass Destruction

1. Introduction

Non-combatants have become an important aspect of U.S. military operations in urban areas. Recent experience shows how non-combatants can affect the United States' ability to meet tactical and strategic objectives in engagements across the spectrum of warfare. However, there is currently little systematic research on civilian behavior within the defense community, including the military modeling community. As the policy questions about dealing with civilians continue to gain in importance, further research on non-combatants would be beneficial. This dissertation reviews recent urban operation campaigns and attempts to provide background research that will assist in incorporating non-combatants into models, simulations, training scenarios, and other analytic tools in a more formal way. It identifies non-combatant behavior from recent urban operations that have affected U.S. military activities. It recommends a layered approach to civilian behavior, beginning with basic population density and other demographic characteristics. To this, it adds simple and then complex behaviors.

This dissertation also assesses methods for modeling large numbers of non-combatants and proposes using agent-based modeling (ABM). Introducing agent-based non-combatants into existing models and simulations also has the potential to extend current force-on-force models and allow them to be used in examining urban operations. This is an important practical consideration and an alternative to waiting, possibly for years, until new urban combat models are built, tested, and formally accredited.

Non-combatants in Recent Operations

Since the end of the Cold War, the United States has conducted several military operations in the midst of civilian populations. It has been involved in peacekeeping, humanitarian relief operations, and other small-scale contingencies that have brought the U.S. military in close proximity to non-combatants. The war on terrorism has also meant an increased tempo of operations in populated areas, particularly in southwest and south central Asia. Overall, the past decade of U.S. experience in Somalia, former Yugoslavia, Afghanistan, and Iraq points to the impact that civilians and military operations can have on one another. Interactions with civilians affect the conduct of a wide range of missions, from humanitarian intervention and peacekeeping to high-intensity urban combat, post-conflict situations, and counterinsurgency operations. There are strategic, operational, and tactical implications for the behavior and presence of non-combatants in large numbers: civilians affect everything from rules of engagement to whether or not certain missions are successful.

It is clear that consideration for civilian casualties affects decisions about the use of force on many levels. At the tactical level, it is factored into everything from air strikes to patrols to force protection. For example, the USAF only used precision guided munitions (PGMs) when conducting air strikes in downtown Baghdad to minimize collateral damage during Operations Desert Storm in 1991.[1] U.S. forces avoided bombing up to three dozen "high priority" targets during the first few days of bombing in Operation Iraqi Freedom (OIF) due to concern for nearby non-combatants. Such targets included the Iraqi Ministry of Defense and some communications facilities.[2] The U.S. Marine Corps (USMC) operated under strict rules of engagement (ROE) during violence in Fallujah in 2004 in an effort to minimize non-combatant casualties.[3] Since September 11, 2001, the war on terrorism also has an important non-combatant component at a more strategic level: U.S. policy makers attempted to show that they were fighting terrorists and not Muslim populations in Afghanistan and Iraq. This not only meant minimizing non-combatant casualties, a highly sensitive issue with the advent of Arab news networks such as Al Jazeera, but also planning for humanitarian relief simultaneously with combat operations. The humanitarian situation in Afghanistan in 2002 prompted the U.S. military to organize food drops. Expectations of widespread refugees and internally displaced persons (IDPs) within Iraq at the start of OIF prompted the U.S. government to plan for a humanitarian disaster.

The presence of non-combatants also adds specific difficulties to troops attempting to conduct operations in an urban environment. They affect urban operations in particular, as (almost by definition) non-combatants are present in the largest densities in cities. Within the urban setting, rules of engagement and concern for non-combatant injuries complicate activities in an environment that is already stressful and challenging. The density of people, both combatant and

[1] United States Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress* (Washington, DC: Government Printing Office, 1992), p. 99.

[2] Eric Schmitt, "A Nation at War: Civilians; Rumsfeld Says Dozens of Important Targets Have Been Avoided," *New York Times*, March 24, 2003, p. B12.

[3] CNN, "How Do Iraqis Obtain RPGs, Missiles?" CNN Live Sunday 16:00, April 12, 2004, Transcript #041103CN.V36.

non-combatant, often provides less time to make decisions than in other terrain.[4] Daily non-combatant travel and other activities can also block movement of U.S. forces and permit opportunities for opponents to blend in and approach U.S. troops and vehicles. The sheer numbers of non-combatants also complicates situational awareness and threat identification.[5] Unexpected civilian responses to combat can also pose dilemmas for troops. During United Nations Operations in Somalia in 1993 (UNOSOM II), non-combatants ran towards the sound of gunfire and protected Adid's men by shielding them with their own bodies.[6] Increased urbanization and the growth of urban populations during the past half-century also have important implications for urban operations. For example, the increase in urban landscape and number of non-combatants means that significantly more personnel may be needed for missions than what would have required few forces decades earlier.[7]

Additionally, non-combatants have considerable power through their own actions to affect the outcome of U.S. military engagements. Somalia is one vivid illustration of how non-combatants can have a dramatic impact on the course of events. Although U.S. forces were successful in accomplishing their mission to arrest two of Mohamed Adid's top supporters, hostile non-combatants in Mogadishu greatly complicated U.S. attempts to exit the city and added to the U.S. death toll. Graphic video of Somalis dragging U.S. bodies through the streets prompted strong public reaction, recriminations from Congress, and halted plans to attempt to capture Adid.[8]

Despite the increased importance of non-combatants in current military operations, the research into non-combatant casualties and non-combatant behavior still lags. In actual battlefield planning, considerable effort goes into vetting air strike targets or to implementing stricter rules of engagement on the ground to minimize non-combatant casualties. However, little attention has been paid to formally understanding the interaction between combatants and non-combatants, with the exception of the literature on peacekeeping operations. There has also been recent work proposing the incorporation of intelligence on

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[4] Russell W. Glenn, Randall Steeb, and John Matsumura, *Corralling the Trojan Horse: a Proposal for Improving U.S. Urban Operations Preparedness in the Period 2000-2025* (Santa Monica, CA: RAND Corporation, 2001), pp. 4-5.

[5] Jamison Jo Medby and Russell W. Glenn, *Street Smart: Intelligence Preparation of the Battlefield for Urban Operations* (Santa Monica, CA: RAND Corporation, 2002), pp. xiii, 34.

[6] Mark Bowden, *Blackhawk Down: a Story of Modern Warfare* (New York: Atlantic Monthly Press, 1999),p. 20; Medby and Glenn, pp. 32-3.

[7] Glenn, Steeb, Matsumura, p. 6.

[8] Bowden, pp. 4, 408-9.

non-combatants as an explicit part of intelligence preparation of the battlefield (IPB) in urban areas.[9] Yet for the most part, military histories, assessments, and lessons learned still generally do not assess strategies for interacting with non-combatants or for minimizing non-combatant casualties.

Even international relief agencies and non-governmental organizations (NGOs) often display gaps in their understanding of non-combatants. For example, before OIF began, the United Nations Under-Secretary-General for Humanitarian Affairs estimated that there would be 2 million internally displaced within Iraq and up to 1.45 million Iraqis who would become international refugees.[10] The United Nations High Commissioner on Refugees (UNHCR) and various NGOs began preparing for a refugee crisis. The reality when the war started was far different from expectations. Some 300,000 Iraqis became internally displaced. However, they were mostly Iraqi Arabs who had been relocated into Kurdish villages under Saddam Hussein and who were now leaving these areas. Instead of a million Iraqis becoming international refugees, roughly 200 crossed into Syria and 1,200 fled into Jordan. Additionally, the group that left for Syria was composed predominantly of third-party nationals: Iranians, Palestinians, and other non-Iraqi Arabs.[11] In short, few Iraqis fled the country and the Iraqis that became internally displaced did so for reasons that NGOs did not anticipate.

Non-combatants in Military Models and Simulations

Parallel to this problem of often overlooking non-combatants in research and analysis in general is the problem of overlooking non-combatants in military models and simulations. Models and simulations are often used in a variety of areas where real-life experimentation is prohibitively costly or unrealistic. Hence there is a particular applicability for defense planners. Models have been used within the defense community for several decades for a wide variety of purposes. These include combat modeling, weapons procurement, technology evaluation, force sizing, military manpower, logistics, information warfare analysis, national strategy, and cost estimation.[12] Models and simulations have

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[9] Medby and Glenn, pp. 7-8.

[10] Clare Graham, "Iraq: Dilemmas in Contingency Planning," *Forced Migration Review*, Issue 17 (March 2003), p.38.

[11] Dawn Chatty, "`Operation Iraqi Freedom' and its Phantom Million Iraqi Refugees," *Forced Migration Review*, Issue 18 (September 2003), p. 51.

[12] Wayne P. Hughes, Jr., ed., *Military Modeling* (Alexandra, VA: Military Operations Research Society, 1984), pp. 4-5; John Matsumura, Randall Steeb, and John Gordon IV, *Assessment of Crusader:*

been used for analysis on issues ranging from strategic nuclear warfare to optimal weapons mix and life cycle costs for weapons platforms.[13] Simulation has also been increasingly used in training and even in recruitment.[14]

Although used extensively by the defense community, models and simulations typically feature few non-combatants. Recent U.S. military operations have often been conducted in close proximity to non-combatants, but the modeling and simulation community has not caught up to this reality. The vast majority of military models still focus on "force-on-force" confrontations despite recent real-life experience. Most modeling scenarios predominantly involve "blue force" and "red force" participants and incorporate only a few neutrals or non-combatants. Combatants heavily outweigh non-combatants in a typical simulation, if non-combatants are used at all. There is also considerable interest at present in improving urban combat models because of ongoing urban operations in Iraq. In the discussion of improving urban combat models, there is often more concern expressed for recreating the exact physical attributes of the urban terrain than there is for realistic non-combatants. Yet basic non-combatant reactions in a situation will shape the environment considerably, and capturing basic non-combatant information in models and simulations may do far more to make models results useful than some of these more elaborate technical features.

Figure 1-1 shows a sample urban combat scenario depicted using the Joint Conflict and Tactical Simulation (JCATS) that depicts few civilians – in green – as opposed to "red" and "blue" actors. However, this does not reflect operational reality. For example, there were 170,000 U.S. and British troops in Kuwait in 2003 who were scheduled to enter Iraq at the start of Operation Iraqi Freedom.[15] Using a 2002 estimate of 5.8 million people living in Baghdad,[16] the ratio of non-combatants to blue force combatants would be approximately 34:1 if

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the Army's Next Self-Propelled Howitzer and Resupply Vehicle (Santa Monica, CA: RAND Corporation, 1998), MR-930-A.

[13] John A. Battilega and Judith K. Grange, *The Military Applications of Modeling* (Wright-Patterson Air Force Base: Air Force Institute of Technology, 1984), pp. 422-8; Arthur Brooks, Steve Bankes, and Bart Bennett, *Weapon Mix and Exploratory Analysis* (Santa Monica, CA: RAND Corporation, 1997), DB-216/2-AF; Francis P. Hoeber, *Military Applications of Modeling: Selected Case Studies* (New York, NY: Gordon and Breach, 1981), pp. 33-60.

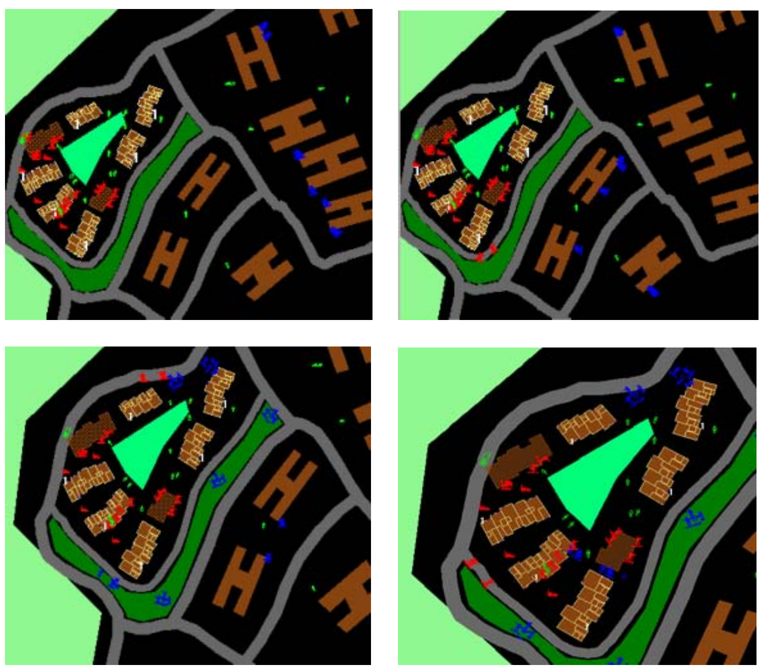
[14] Richard W. Pew and Anne S. Mavor, ed., *Modeling Human and Organizational Behavior: Application to Military Simulations* (Washington D.C.: National Academy Press, 1998), p. 49; and "America's Army," a downloadable computer game geared towards potential recruits, accessed at www.goarmy.com/aagame/index.htm on March 12, 2004. For tournament play and more information, go to www.americasarmy.com.

[15] Tommy Franks with Malcolm McConnell, *American Soldier* (New York, NY: HarperCollins Publishers, 2004), p. 434.

[16] "Iraq: Key Facts, November 19, 2003," *World of Information Country Report*, Quest Economics Database; accessed through Lexis-Nexis on March 12, 2004.

all these troops had entered Baghdad. If one tenth these troops were in Baghdad at any given moment, they would have encountered a ratio of 340 civilians per soldier or Marine. This is in stark contrast to many analytic models that portray a few non-combatants running around in a sea of combatants. Yet actual experience strongly indicates that overwhelming number of non-combatants can have significant operational effects: it would be ideal to capture this element in combat and stability and support models as well.

Figure 1-1. Sample Urban Combat Scenario in JCATS (Few Civilians)



Aside whether or not non-combatants may need to inhabit military simulations on a vaster scale, additional work needs be done to produce more realistic behavior. Non-combatants in existing models are sometimes stationary, not programmed to react to events around them (such as combat), and are usually identical to one another. Ideally, simulated civilians would move, interact with combatants and their environment, and exhibit different behaviors to better reflect real-world complexities. It would also be best to populate military models with non-combatants whose behavior is similar to what has been observed in actual urban conflicts. Aggregate information on non-combatant movement, activities, and casualties would be useful for lower-resolution models. Such aggregate data would also be useful for calibrating both high-resolution and low-resolution models. Detailed information on individual-level behavior should be helpful for replicating more realistic non-combatant behavior in higher-resolution models.

There are some current efforts that promise to better incorporate non-combatants into models and simulations in the future. For example, Urban Resolve is a program being run by the U.S. Joint Forces Command (USJFCOM) J9 Directorate and the Joint Advanced Warfighting Program (JAWP) and the Institute for Defense Analysis on finding new approaches to urban combat. Urban Resolve involves advancing urban combat simulation and increasing the density of civilians in simulations.[17] However, even Urban Resolve calls for fewer civilians than may be realistically expected in the type of urban terrain that is envisioned in the program. Anticipated civilian behavior is also currently limited to traveling and does not touch upon more complex or interactive behavior.

Combat modeling is difficult. Because they are abstractions from reality, most models cannot fully reflect the complexities of the phenomena they are designed to represent.[18] This is especially true of models that incorporate human behavior and decision making. Warfare models fall into this category. They incorporate human as well as physical effects, and the complex nature of warfare makes realistic combat modeling a difficult challenge. At the same time, they are valuable tools and there appears to be room for continuing improvements. There has been an effort to introduce more realistic human behavior representation in military models where individual responses and organizational behavior affect outcomes. For example, greater use of psychological research on decision making, memory, and group behavior enhance representation of individual combatants and units.[19] Although most of this qualitative research has been done to improve the modeling of combatants, similar research could also be conducted to enhance the representation of non-combatants. Increasing the number of non-combatants and introducing more realistic non-combatant behavior would add realism to military models and allow models to incorporate an important policy consideration.

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[17] Andy Ceranowicz and Mark Torpey, “Adapting to Urban Warfare,” Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2004, Paper No. 1554, pp. 1-5.

[18] Notable exceptions include models and simulations of physical phenomena, such as light, gravity, etc.

[19] Pew and Mavor, pp. 10-11, 20.

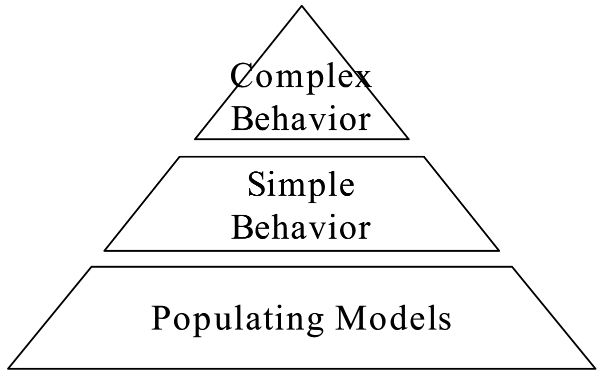
Research Approach

This dissertation uses case study methodology to review the U.S. military experience in three recent urban operations. The case studies are: Operation Just Cause (Panama), UNOSOM II (Somalia), and Operation Iraqi Freedom (Iraq). Based on information gathered in the case studies, it recommends behavioral rules for non-combatants in military models. Agent-based modeling appears to be a good approach for simulating non-combatants and is the framework that is used. ABM allows individual agents, acting upon internal rules, to interact with their environment and with other agents. It also allows for emergent and adaptive behavior on the part of agents. ABM will be further discussed in the methodology section. The literature on ABM specifically within military modeling is also highly relevant and will also be discussed in greater depth.

Non-combatant behavior is discussed using a layered approach. The first "layer" of non-combatant behavior consists of how to populate models with non-combatants. The second layer of non-combatant behavior consists of simple behaviors such as basic background movement and basic reactions to combat. The third layer of behavior consists of more complex behaviors, including interactions between combatants and non-combatants. These layers of behavior are intended to build on one another and to identify policy-relevant behaviors that may be fairly easily modeled. This dissertation is in no way intended to be a comprehensive compendium of non-combatant behaviors and how they should be modeled. Rather, it is an introductory effort aimed at approaching non-combatants in military models in a more systematic way than it has been done so far. This layered approach is illustrated in Figure 1-2.

This dissertation contributes to knowledge in two ways. First, there is no work to date that examines non-combatant behavior across cases. This dissertation discusses behavior and important facts about civilians that have had implications for recent urban operations. This information should be of general interest to decision makers dealing with urban operations and of specific interest to anyone engaged in urban operations modeling or analysis. The second set of insights is how the ABM framework might be used to model non-combatants. The chapters of simple and complex behaviors are particularly geared towards those using ABM in combat and MOOTW simulations.

Figure 1-2. Layered Approach to Non-combatant Agents in Military Models and Simulation



Dissertation Organization

Chapter Two covers methodology. It begins with a discussion of case study methodology and the reasons for why this is appropriate for this analysis. It also gives an overview of ABM and reviews some of the general literature on ABM and social phenomena. The third section of Chapter Two discusses the literature on current uses of ABM in military modeling. The final section of the chapter reviews modeling successes using ABM in areas that are relevant to non-combatant behavior. It also discusses how ABM might be used to salvage existing constructive, force-on-force models and makes the case for proposing ABM over other approaches for representing non-combatants.

Chapter Three discusses case study criteria and presents finding about civilian behavior in the three case study operations. It also identifies the behaviors that will be discussed in the rest of the dissertation.

Chapters Four, Five, and Six discuss non-combatant behavior and are structured around a layered approach to introducing them into military models. The dissertation begins with the simplest consideration in Chapter Four: populating models with non-combatants. The chapter emphasizes the operational and analytic importance of accounting for the correct scale of the civilian population. It deals with population size, density, and demographic factors, using information from the case study cities and other urban areas to illustrate policy implications.

Chapter Five discusses simple civilian behaviors from the case studies, including background movement and simple reactions to combat. It discusses the significance of these behaviors and some ways that better understanding of these behaviors could improve U.S. interactions with local populations. The chapter also examines these behaviors specifically in the context of ABM, and the added analytic capabilities that would result from including these behaviors into models.

Chapter Six reviews complex civilian behaviors and civilian interactions with combatants from the case studies. It discusses the operational and policy significance of these behaviors. This chapter also contains a section that deals with modeling complex behaviors using ABM.

Chapter Seven reviews the layered framework discussed in the preceding chapters and discusses broader policy implications of having analytic tools that better incorporate civilians in urban operations. The chapter ends with directions for future research.

2. Methodology and Literature Review

Chapter Two covers methodology and the pertinent literature. The first section covers case study methodology and discusses why it is appropriate for examining non-combatant behavior in urban operations. The second section introduces agent-based modeling and covers the general literature on using ABM to model social phenomena. The third section discusses the literature that is available specifically on using ABM in military models and simulations. The final section of this chapter discusses why ABM is an appropriate approach to depicting non-combatants in military models and simulations.

Case Study Methodology

This dissertation uses case study methodology to review three recent U.S. urban operations for non-combatant behaviors. It reviews a variety of sources for each case to gather information about non-combatant behavior, casualties, and the interaction between non-combatants and combatants. Materials include official histories, newspaper reports, and NGO information.

Case study methodology is ideal for understanding non-combatant behavior in urban operations. It is best when a "holistic, in-depth investigation" is desired into a phenomenon. Urban operations are complex events with multiples viewpoints; case studies are appropriate because they are multi-perspective. Case studies are also a good choice for this subject because they constitute a "triangulation research strategy" for dealing with multiple types and sources of data.[20] In total, the methodology offers four kinds of triangulation: data source triangulation, investigator triangulation, theory triangulation, and methodological triangulation.[21] This "triangulation" feature makes it a good candidate for dealing with non-combatant behavior during urban operations. When dealing with non-combatant behavior, there are multiple data sources, multiple points of view, and even different theories on what caused such behavior. There are six types of data sources for case studies: documentation,

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[20] Winston Tellis, "Applications of a Case Study Methodology," *The Qualitative Report*, Vol. 3, No. 3, September 1997. Online journal. Internet: accessed at www.nova.edu/sss/QR/QR3-3/tellis2.html on February 19, 2004.

[21] Tellis.

archival records, interviews, direct observation, participant observation, and physical artifacts.[22] This dissertation deals primarily with documentation such as written accounts.

Case studies are often used to establish causality. Social science research in fields such as political science is often concerned with explanatory analysis that build or test causal models. However, this dissertation is more interested in describing the non-combatant behaviors that occur in the case studies than in making the case for causal mechanisms. One reason is that causal studies do not always have the most direct implications for policy research. They may in health care and other areas where interventions are easier to monitor and control. Yet in areas such as urban operations, the shear complexity of compounding factors easily outweighs the information learned about the effects of isolated factors. A second reason is that modeling and simulation is less concerned with causality than identifying the existence of relationships and how those relationships may interact. For instance, in modeling it may be acceptable to combine many inputs into one whereas in causal theory building and explanation this type of simplification would be inappropriate. Hence, this dissertation focuses more on exploring non-combatant behaviors, the relationship between behaviors, and the relationship between non-combatants and combatants than it does on explaining why certain behaviors arise under what circumstances. Although there is some discussion of the latter, it is not the chief purpose of this research effort.

Besides case studies, other qualitative techniques exist that could possibly be employed to understand and to suggest rules for non-combatant behavior. However, many of these alternatives are less than ideal for understanding social behavior during times of war because circumstances are so tumultuous. For example, ethnographic decision modeling (EDM) is a technique used in anthropology to build causal models on decision making under specific circumstances. It creates decision trees on why fishermen decide to fish in a given location or how people choose treatments for illnesses.[23] It might theoretically be employed to describe how non-combatants make decisions to leave or enter cities during conflict, for example. However, gathering data to construct such a tree requires interviews with people who both made and did not make a given decision. It also requires open-ended interviews to construct decision pathways and additional interviews to test theories built from such

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[22] Tellis; Robert K. Yin, *Case Study Research: Design and Methods*, second edition (Thousand Oaks, CA: Sage Publishing, 1994), pp. 79-90.

[23] Gery Ryan, "Ethnographic Decision Modeling (EDM)." Internet: accessed at web.Missouri.edu/~anthgr/papers/Bibs/EDM.htm on January 15, 2004.

initial interviews.[24] To apply this technique, it would require traveling to Iraq, Somalia, and Panama; employing translators; and finding and interviewing non-combatants who had both engaged in a behavior of interest and who had not. These requirements often make EDM impractical for understanding non-combatant decisions made during times of conflict.

Agent-based Modeling

Agent-based modeling appears to be a suitable modeling approach for non-combatants in military models and simulations. This section provides an introduction to ABM and reviews portions of the ABM literature. The purpose of the literature review is to lay the groundwork for assessing the applicability of ABM to modeling non-combatants. It also discusses how behavioral rules for agents are typically constructed in ABM research. Because non-combatant behavior is a social phenomenon, the primary focus of the literature review in this section is on the use of ABM in the social sciences. It excludes the more technical uses of ABM within computer science and the use of ABM to model purely biological activities such as the behavior of ant colonies and the propagation of coral reefs. However, it touches upon some of the work in evolutionary biology because of its connection to the literature on cooperation and norms. The literature on ABM in military modeling is reviewed separately in the following section.

The work by Thomas Schelling on self-segregating neighborhoods is considered by many to be the first execution of an agent-based model.[25] Using dimes and pennies represent homeowners of two different races and a grid to represent neighborhoods, Schelling gave his agents a simple set of rules to follow. Each "race" was willing to tolerate up to a certain percentage of its neighbors being of the other race: dimes wanted at least half of all their neighbors to be dimes, and pennies wanted at least one third of their neighbors to be pennies. An agent would examine its immediate neighbors. If the percentage of other-race agents was below this threshold, it would stay; otherwise, it would move. Schelling found emergent patterns when his agents acted upon these rules about neighbor preferences. This emergent behavior

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24 Phone interview with Gery Ryan at the RAND Corporation on qualitative research methods, January 15, 2004, Santa Monica, CA.

25 Joshua M. Epstein and Robert Axtell, *Growing Artificial Societies: Social Science from the Bottom Up* (Washington, D.C.: Brookings Institution Press, 1996), p. 3; and Alessandro Lomi and Erki R. Larsen, *Dynamics of Organizations: Computational Modeling and Organization Theories* (Menlo Park, CA: AAAI Press, 2001), p. 8.

showed patterns of self-segregation and mimicked real-world neighborhoods that "tipped" even though agents are fairly tolerant.[26]

Thomas Schelling simulated this first ABM using coins. Since then, ABM has become closely associated with computer simulation and is being applied to a growing number of topics and research questions. The declining cost of computing power makes computation exploration such as ABM possible on a scale that was not possible in previous decades. (Sometimes the phrase "multi-agent model" is used instead of "agent-based model".)[27] ABM has been employed in an ever-widening number of areas because of its flexibility and relative ease of use. It is able to link individual behavior to emergent trends. ABM also scales readily and is able to handle heterogeneous and adaptive agents – a feat not easily accomplished by many other modeling approaches.[28] ABMs are often employed when dealing with complexity, non-linear phenomena, and non-equilibrium outcomes.[29] It is a natural fit for complex adaptive systems (CAS) where non-linearities mean that the behavior of a system as a whole is more than the sum of the behavior of its parts.[30] ABM has also been called a "natural description" of a system that includes behavioral components.[31] This has made it a fitting tool for research on complex social phenomena.

A basic ABM consists of autonomous agents and emergent behavior. Instead of being scripted or being reliant on a central program to determine their actions, autonomous agents interact with one another and make individual decisions based on internal criteria and information about their immediate environment.[32] For example, Schelling's agents decided to move or to remain depending on their desired mix of neighbors and the mix that they perceived. The emergent behavior was a pattern of self-segregating neighborhoods.[33] In addition to autonomy, agents typically exhibit social ability through interactions

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[26] Thomas C. Schelling, *Micromotives and Macrobehavior* (New York, NY: W.W. Norton & Co., 1978), pp. 147-66.

[27] Nigel Gilbert and Klaus G. Troitzsch, *Simulation for the Social Scientist* (Buckingham and Philadelphia, PA: Open University Press, 1999), pp. 158-9.

[28] Robert Axtell, "Why Agents? On the Varied Motivations for Agent Computing in the Social Sciences," Brookings Institute, Center on Social and Economic Dynamics, Working Paper No. 17, November 2000 (Washington D.C.: Brookings Institute, 2000), pp. 2-3, 5.

[29] Axtell, p. 2-3.

[30] John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Cambridge, MA: Perseus Books, 1995), pp. 4-5. CAS is also marked by "coherence under change" and often by an amplifier effect, where small changes act as an amplifier on larger parts of the system.

[31] Eric Bonabeau, "Agent-based Modeling: Methods and Techniques for Simulating Human Systems," *Proceedings of the National Academy of Sciences*, Vol. 99 (May 14, 2002), p. 7281.

[32] Bonabeau, p. 7280; and Gilbert and Troitzsch, p. 159.

[33] Schelling, p. 153-5.

with other agents, reactivity to their environment, and initiative in pursuing their goals.[34] Agents in a model are typically given goals, such as finding an acceptable mix of neighbors, traveling to a destination, finding food, making money in the stock market, or deciding to adopt technology, to name but a few of the objectives they have been given.

Agents in ABMs may also be heterogeneous, adaptive, or both.[35] In addition to different classes of agents, agents within classes may also be heterogeneous in parameters, behavioral rules, endowments, information, rationality, and other attributes. Heterogeneity across a large enough variable space even allows for a population of unique individuals. When agents are adaptive, they are able to change strategies and behavior based on changes in their environment. Heterogeneity and adaptive behavior are often used in tandem with one another to identify agents or strategies that are best suited to survive over time, and to identify potential long-term trends.[36] On the other hand, it is quite possible to have a useful ABM without adaptive agents *or* heterogeneous agents. For example, Schelling's agents do not have adaptive behavior (they cannot change their preferences or their strategies) but are able to offer an explanation for how neighborhoods became self-segregating. Another example is the work on crowd panic situations. Although agents in this literature tend to be homogeneous and non-adaptive, models still yield valuable insight into preventing deaths in panic scenarios.[37]

Despite its strengths, ABM also carries disadvantages when used in research. Perhaps the biggest disadvantage is the question of generalizability. Precisely because ABM outcomes tend to be non-linear, this poses a difficulty:

> Nonlinearities mean that our most useful tools for generalizing observations into theory – trend analysis, determination of equilibria, sample means, and so on – are badly blunted. The best way to compensate for this loss is to make cross-disciplinary comparisons…in hopes of extracting common characteristics.[38]

While also acknowledging the problem of generalizability, one proposed way to address this concern is merely to conduct multiple runs of a simulation:

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[34] Gilbert and Troitzsch, p. 159.

[35] Holland, pp. 10-15, 19-20.

[36] Robert Axelrod, *The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration* (Princeton, NJ: Princeton University Press, 1997), p. 15.

[37] Dirk Helbing, Illes Farkas, and Tamas Vicsek, "Simulating Dynamical Features of Escape Panic," *Nature*, Vol. 407, September 28, 2000, pp. 487-90.

[38] Holland, p. 5-6.

> Despite the fact that each run of such a model yields is a sufficiency theorem, a single run does not provide any information on the robustness of such theorems. That is, given that agent model *A* yields result *R*, how much change in *A* is necessary in order for *R* to no longer obtain? In mathematical economics such questions are often formally resolvable via inspection, simple differentiation, the implicit function theorem, comparative statistics, and so on. The only way to treat this problem in agent computing is through multiple runs, systematically varying initial conditions or parameters in order to assess the robustness of results.[39]

However, there is a serious problem with the idea that multiple runs are all that is needed to solve the problem of generalizability for ABM model results, particularly when applied to social phenomena. As with any model, an ABM is an abstraction and is not reality itself. Again excluding models of well-understood physical phenomena, simulation results are not the same as data. To treat them as such, as some in the literature are prone to do, gives too much weight to model results without offering other sources of proof. Instead, it seems best to use simulation results to generate possible theories, or to use a simulation is tandem with other data and arguments to support policy decisions.[40] On the other hand, when simulations are used to illustrate what is known and to demonstrate past events in a specific operation, there are fewer issues with generalizability. (Such applications are useful in training.) If ABM were used in this way, it would avoid this key weakness of the approach. For example, this dissertation will make qualitative generalizations about non-combatant behavior from three case studies and then suggests ways to incorporate these findings into ABMs and other military analysis.

Every year there is more published works that use ABM. One way it is used is for theoretical inquiry and experimentation in topics where simulation is useful because real-life experimentation is not practical. These types of research areas include anthropology, archeology, economics, behavioral finance, evolutionary biology, sociology, and political science. There is work that simulates ancient household migration patterns, game theory, norms and altruistic behavior, asset pricing and stock markets, organizational behavior, technology diffusion, political sorting, the emergence of states, and banding behavior in rhesus monkeys. A second way to employ ABM is in analysis used to inform decision makers in both public and private sector settings. Examples of these topics include research into crowd panic behavior, smallpox

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[39] Axtell, p. 3.

[40] Questions about generalizability are hardly new for members of the defense modeling community and it is unlikely to prose dramatic new problems for model users. That is, the main disadvantage to ABMs is actually a disadvantage inherent to the use of models and simulation in general.

transmission, operational risk analysis, greenhouse gas emissions trading, traffic jams, lines in theme parks, and civil violence. A third use of ABM is for entertainment purposes. Examples of this include computer games such as SimCity and simulations used in movies such as the *Lord of the Rings* trilogy.[41] The research discussed in this literature review is not without shortcomings. In some cases, there is a tendency to be overly enamored of the technique and less concerned with the craft of building models. However, they do illustrate the range of phenomena that can be plausibly explored with ABM.

There are several works that serve as introductions or overviews of ABM. Among these are Holland (1995), Parunak, Savit, and Riolo (1998), Gilbert and Troitzsch (1999), Rauch (2002), Axtell (2000), Bonabeau (2002), Elliott and Kiel (2002), and Conte (2002). Holland, the originator of genetic algorithms, provides a clear and excellent manual for those interested in building their own ABMs. Holland discusses objectives, agents, and adaptation. His seven basics of a complex adaptive system (CAS) are: aggregation, tagging, nonlinearity, flows, diversity, internal models, and building blocks. He further discusses adaptation and emergent behaviors. Parunak, Savit, and Riolo introduces ABM as an alternative to equation-based modeling (EBM). Gilbert and Troitzsch briefly discuss ABM in their volume on simulation for social scientists. These two authors cover the basics and uses an ABM of ant colonies as an example.

Written for a general interest magazine, Rauch covers a few well-known models by Schelling, Epstein, and Axtell. In contrast to Holland, Rauch's purpose is to offer an intuitive feel of how ABM may be used rather than to provide technical clarity on its construction. Axtell discusses the strengths and weaknesses of ABM compared with other simulation techniques that may be applicable to fields such as economics. Bonabeau, Elliott and Kiel, and Conte were papers published in the same issue of the *Proceedings of the National Academy of Sciences*. Bonabeau offers an overview of ABM and its benefits. He also discusses its application in describing flows, markets, organization, and diffusion. Elliott and Kiel give a brief overview of ABM in simulating competitive and cooperative behavior in social science research. Conte discusses ABM's applicability to individual and social intelligence.

In addition to these general ABM discussions are articles and books that use ABM in a specific application. First, there are examples of ABMs for theoretical inquiry. As previously discussed, Schelling (1978) uses ABM to

[41] New Line Cinema, *Lord of the Rings: the Two Towers* Extended DVD, 2003. See the feature on computer generated effects.

explore assumptions about neighbor preferences and the self-segregation patterns that emerge. Another well-known ABM of social behavior is the Sugarscape model created by Epstein and Axtell (1996). Epstein and Axtell create a world where agents harvest and consume sugar in order to survive and reproduce. Moving across a landscape, agent survival is affected by such things as vision and metabolism. From this simple start, the authors discuss such social phenomena as the distribution of income (sugar), migration patterns, genealogical networks, fertility, cultural transmission, evolution, cultural tags, and even combat. This happens as they make modifications to agent rules and characteristics to induce more complex behavior. Introducing a second commodity, spice, brings about markets, trade, and demand and supply curves. Epstein and Axtell then go on explore disease transmission and immunity in their world. The authors raised the question of policy implications from the economic markets that resulted from sugar and spice. However, most of the discussion in this work appeared relevant for theoretical inquiry. The Sugarscape world took ABM and showed its potential applicability to a number of social science fields.

Epstein, Axtell, and fellow researchers affiliated with the Brookings institute have produced additional work that attempts to apply ABM to cross-disciplinary inquiry as well as to policy problems. Axtell (1999) uses ABM to explore the emergence of different sizes of firms. According to Axtell, agents sort themselves into different sized firms based on heterogeneous preferences for income and leisure. The output of firms increases as agents join, but then an agent's individual payoff for more effort diminishes. Those with strong preferences for income then leave the firm as it grows, and output diminishes. Arguing that the simulated distribution of firm sizes is consistent with that found among actual U.S. firms, Axtell concludes that theories of the firm centered on microeconomic equilibriums are unable to account for many real-life phenomena. Axtell's work on the firm uses microeconomic theory and adds heterogeneous agents and assumptions about self-sorting. The author makes the controversial argument that current methods of evaluating equations in economics are insufficient to capture real economic processes. Another example is the work by Axtell, Epstein, and Young (2000) on the emergences of classes. The authors discuss the emergence of classes in an artificial society that have norms and social expectations. This is another piece that is primarily used for theoretical exploration.

The use of ABM in the literature on conflict and cooperation is another example of using ABM primarily for theoretical inquiry. Simulation is particularly useful in understanding the implications of game theory. Authors such as Axelrod (1997) borrow from the evolutionary biology literature when exploring game theory. Building on his previous work on reiterated Prisoner's Dilemma games,[42] the author creates a world where agents are instructed to cooperate or defect in different time periods depending on their "genetic" code. The use of genetic algorithms and random mutations allows for adaptation and the emergence of new strategies. At the same time, preferential replication of more successful strategies allows the population to "evolve" towards more successful cooperation strategies. Based on computational runs of such a program, Axelrod concluded that Tit-for-Tat like strategies, those that cooperate or defect based on the opponent's previous move, offer the largest gains and emerge as the "best" cooperation strategy.[43] Axelrod's work is widely cited in discussion on topics including international trade, the evolution of norms, and the nuclear standoff between the superpowers during the Cold War. It is debatable how "realistic" Axelrod's assumptions are. However, the outcome of these ABMs was of theoretical value for a number of different subjects that deal with the question of why cooperation emerges.

Another example of using ABM for academic theoretical inquiry is work by Cederman (1997) on the emergence of states and nations. Cederman uses models of actors in international politics to test for the emergence of different types of international systems (unipolar, bipolar, multipolar) under varying assumptions such as offense dominance, defense dominance, and the existence of defense alliances. He then complicates his basic model by introducing different assumptions about alliances, adaptation, and other factors. Cederman bases many model and behavioral assumptions on political science theory and uses his findings for further discussion on theory. ABM's allowance of self-sorting behavior makes its application to international relations theory an interesting one because small units are allowed to merge or break off. Additionally, his decision to have many of this behaviors and rules grounded it theory from the field makes the outcomes relevant for theoretical discussion.

Kollman, Miller, and Page (1997) apply ABM to the question of political sorting. They simulate Tiebout models, where citizens sort themselves among different jurisdictions depending on their preferences and the bundle of public goods that each jurisdiction offers. Kollman, Miller, and Page evaluate the performance of different simulated political institutions in allowing citizens to maximize their preferences. They also allow jurisdictions to be adaptive,

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[42] Robert Axelrod, *The Evolution of Cooperation* (New York, NY: Basic Books, 1984).

[43] Tit-for-Tat is a strategy that plays the opponent's previous move in a reiterated Prisoner's Dilemma game. In computer tournaments held by Axelrod and discussed in *The Evolution of Cooperation*, Tit-for-Tax emerged as the winning strategy.

changing their public goods in response to citizen preferences. The authors compare different political institutions: democratic referenda, direct competition with varying numbers of parties, and proportional representation with varying numbers of parties. Kollman, Miller, and Page are then able to discuss the political institutions that maximize citizen utility assuming different numbers of jurisdictions and different numbers of political parties. This paper was done primarily from a theoretical point of view and adds to the literature on Tiebout models. At the same time, it is not difficult to see how such work might have policy relevance when creating political institutions for a new democracy.

The Sante Fe Institute is perhaps the best-known institution connected with the study of complexity. Although much of their work is beyond the scope of this literature review, the institute has also been associated with the application of ABM to social phenomena. The volume edited by Kohler and Gumerman (2000) compile several works by anthropologists and archeologists who have used ABM in their research. Works include simulation of primate aggression and social groups; the evolution of warning calls; the evolution of signals; the role of beliefs and emotions in artificial societies; patterns of Mesolithic foraging; settlement development among pueblo populations; the emergence of common property; and the political impact of marriage on Polynesian society. These works show how ABM is a powerful simulation tool that may be used for theoretical exploration in these two fields. When behavior is based on existing theory, model results may aid in enriching the theoretical debate within an academic discipline. Kohler and Gumerman show how flexible ABM can be as a tool in investigating a wide variety of human and animal behavior when real experimentation is impossible. Simulation of plausible migration and settlement patterns of long-gone human populations allows researchers to theorize about the sudden disappearances of a culture. It also allows for archeologists and anthropologists to make assumptions about social behavior and “test” the social patterns that might have emerged.

Again, two other fields that are increasingly experimenting with simulation in general and ABM in particular are economics and finance. As noted above, Axtell addressed microeconomic theories of the firm in his work on firm sizing. ABM also appears to be well suited to simulating markets and has been used both to explore financial theory and to predict the consequences of changes in financial institution rules. Again, there are several works in this area and the few that are included in this literature review merely constitute a sampling. Arthur, Holland, LeBaron, Palmer, and Tayler (1996) explore asset pricing in artificial stock markets.[44] Arthur, et. al. argue that because expectations in a market depend on anticipating others' expectations, assets markets are recursive and cannot be deduced from a set of assumptions. Instead, the authors use ABM to model expectations and test two theories of asset markets: standard efficient-market theory versus "market psychology" beliefs. In an interesting result, Arthur, et. al. found that in their simulations, allowing agents to explore a high number of alternative models of other agents' expectations resulted in the simulation of a complex market with many of the features of a real market. There were bubbles, crashes, technical trading, and market measurements that reflected the statistical behavior of actual markets. On the other hand, permitting only a low rate of belief exploration led to the standard "efficient" market.

In addition to these types of works are those whose primary purpose is to inform specific decisions or to support policy analysis. In some cases there is an overlap between theoretical inquiry and results that have policy applications. Here, theoretical inquiry produces results that may be acted upon. In other cases, the research was constructed around a policy problem and is not concerned with testing academic theories against each other. Although "policy" is usually associated with decisions in the public sector, studies focused on decision making in the private sector are included in the paragraphs below as well. Regardless of the type of decision maker that this type of ABM research is intended to benefit, the key distinguishing feature is the use of ABM to inform specific decisions rather than as an instrument of academic theoretical inquiry. Although behavioral rules might be informed by theory, the purpose is usually to build a realistic simulation that might be used to gauge potential decisions. (Policy makers facing decisions about non-combatants in urban operations fall into this category.) This is in contrast to the purpose of many of the works mentioned above, which seek to evaluate theories of behavior or to help create new ones. Generally for policy purposes, there is less concern that behavioral rules be consistent with any kind of formal theory. Instead, the criterion appears to be that rules are reasonable or plausibly reflect a behavior of interest. This is particularly true when research is exploratory or mainly concerned with strategy robustness over a space of parameters.

One notable area of policy applicable ABM research is the study of pedestrian and vehicle traffic flows. Helbing, Farkas, and Vicsek (2000) discuss simulating crowd panic behavior and stampedes. Basing panic behavior on psychology theory and modeling the physical forces involved in crowds

[44] These authors were also affiliated with the Sante Fe Institute.

pressing against each other, the authors produce a model of people stampeding and converging on an exit. Helbing, Farkas, and Vicsek are able to simulate bottlenecks and to measure the flow of people successfully emerging from an exit as well as the number of injuries that result. Agents were homogeneous. This work departs from traditional work on pedestrian behavior, which typically (and incorrectly) applied fluid dynamics to pedestrian flows.[45] Helbing (2003) goes on to discuss other phenomena such as self-directed pedestrian lanes, "phantom" traffic jams, route selection when traveling, and standing human waves at sporting events. One interesting recommendation from Helbing (2003) is the idea that columns near an emergency exit can actually improve flow and result in fewer injuries during panic situations.

Still (2000) is another in-depth look at crowd panic behavior. Still formulates rules to simulate a number of behaviors in places such as stadiums. The author notes behavior such as the spontaneous formation of directional pedestrian lanes within a crowd and takes note of turnstile data to better understand flow. In general, Still derives rules for agent behavior from visual observations of crowd movement. Unlike the agents used by Helbing, Farkas, and Vicsek, the ones used in Still's simulation do not have a round ground imprint but an oblong one to simulate shoulders. Still also notes the heterogeneity of area taken up by individuals, offering statistical data based on race, ethnicity, and gender. Based on his rules of crowd behavior and incorporating queue theory, Still is able to evaluate emergency exits, corridor geometry, and other factors that affect flow in a given stadium or building.

Works by various authors affiliated with the Brookings Institute also point to the possibility of using ABM across a number of different policy areas. Epstein, Steinbruner, and Parker (2001) use ABM to model civil violence. In their first model, the authors attempt to simulate "generalized rebellion against a central authority." This first model has an agent rebel when its grievance level, a function of hardship and perceived legitimacy of the central authority, is sufficiently high enough to overcome the agent's risk aversion. The model also employs "cops" who can arrest agents and remove them from the population. The second model used in the paper is one that represents ethnic violence. In it, ethnic cleansing happens when groups do not perceive each other as having a right to exist. Genocide typically emerges unless peacekeepers are present. Epstein, Steinbruner, and Parker discuss the phenomena of genocide and the potential policy implications of preventing it. Rules for the two models do not appear to be based on theory, but appear to be set to reflect reasonable

[45] David J. Low, "Following the Crowd," *Nature*, Vol. 407, September 28, 2000, p. 465.

assumptions about what behavior might be. Gulden (2002) is a related work, also from Brookings. The paper is concerned with ethnic mix and ethnic violence. Gulden finds a non-linear relationship between ethnic mix and the number of deaths due to ethnic violence during civil conflict in Guatemala from 1977 to 1986.

Epstein, et. al. (2002) use ABM to produce policy recommendations for containing smallpox during a bioterrorism attack. Agents within this world commute back and forth between home, work, or school. Infection rates for different locations are based on historic data for smallpox outbreaks in Europe during the 20th century. Using this simulation, the authors evaluate different strategies to halt the spread of the disease: trace vaccination of those who had close proximity to victims, mass vaccination, and combined vaccination strategies. Epstein, et. al.'s approach to understanding the dynamics of smallpox transmission differ from more traditional equation-based models that assume perfect mixing. Calibrated with historic data, the simulation illustrates smallpox transmission using all available knowledge. In this work, behavioral rules reasonably approximated commuting and other daily activities. Transmission, death rates, and recovery rates were based on historic data.

Environmental policy is another area where ABM is being used to evaluate strategies. Lempert (2002) uses an ABM of technology diffusion to compare different strategies for controlling global climate change. Agents with heterogeneous beliefs adopt different technologies based on expectations of performance and cost. Actual costs depend on the number of agents who do in fact adopt the technology. Energy prices and greenhouse gas (GHG) emission are affected by the technology that agents adopt. The model also includes policy levers such as carbon taxes and technology incentives. Lempert uses the model to test the robustness of different policies over a range of different parameter values for variables such as environmental damage. Agent behavior in Lempert's model also reflects potentially reasonable behavior, rather than behavior based on academic theory. Mizuta and Yamagata (2001) also apply ABM to model policies designed to curb GHG. Based on previous work by the authors on commodity markets, Mizuta and Yamagata set up virtual online auctions to simulate GHG trading under the Kyoto Protocol. The paper argues for the suitability of ABM to model similar systems and calls for further research on GHG emissions trading using this technique.

ABM also has the potential to be very useful for private business applications. For example, it can be used for organizational simulation. Because organizational behavior may be represented as emergent behavior, ABM can be used for such purposes as evaluating operational risk.[46] Another way that ABM may be employed is to assess technology diffusion within an organization. Parunak, Savit, and Riolo, apply ABM to model supply chains. When combined with the literature on behavioral finance, ABM may also produce recommendations for organizations that deal with financial markets. One very interesting project conducted by the Bios Group simulated potential changes to the National Association of Security Dealers Automated Quotation (NASDAQ) trading rules. The NASDAQ proposed to reduce the smallest increment in stock price from 1/8th of a dollar to one cent, in hopes of increasing the ability of traders to perform price discovery and hence decrease the bid-ask spread on prices. However, the Bios simulation accurately forecasted that reducing the smallest increment in pennies would result in *reduced* price discovery and *higher* spreads. This prediction was borne out in real life when the NASDAQ did in fact move to decimalize their prices and spreads increased.[47]

ABM and Military Modeling

For many of the same reasons outlined above, ABM is currently being applied to combat models. Complexity – the emergence of macrophenomena from many moving parts – and non-linearity are concepts that may also be applied to warfare and the military modeling community has been well aware of the possibilities.[48] ABM also allows to models to take aspects of combat into account that are difficult to model with other approaches. For example, the random nature of agent interactions in an ABM is closer to the stochastic nature of real life combat. Attrition and detection are also random to an extent.[49] It is also argued that actual battles themselves are non-linear and often contingent on "probabilistic 'swing events'" of the sort that ABM is known to handle well.[50] Precisely because of this ability to deal with non-linearity, ABM advocates maintain that the technique is better at replicating non-linear realities that

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46 Bonabeau, p. 7284.

47 Bonabeau, pp. 7283-4.

48 Robert Axelrod, *The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration* (Princeton, NJ: Princeton University Press, 1997), p. 3; M. Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York, NY: Simon & Schuster, 1992): 9-12; and Andy Ilachinski, "Towards a Science of *Experimental Complexity*: An Artificial-Life Approach to Modeling Warfare," (Alexandria, VA: Center for Naval Analysis), pp. 1-3.

49 Thomas W. Lucas. "The Stochastic Versus Deterministic Argument for Combat Simulations: Tales of When the Average Won't Do," p. 19; internet: accessed at http://diana.or.nps.navy.mil/~twlucas/My%20papers/SVD.pdf on March 17, 2004.

50 Lucas, pp. 1, 5, 8.

doctrine acknowledges but that model results often do not show. Additionally, ABM can be used to better reflect intangibles in warfare such as morale or personality. A number of military models have already begun using ABM to better simulate command and control processes, human adaptability, strategic effects, and other factors that were previously difficult to incorporate.[51]

There is already a considerable research effort dedicated to ABM and military modeling. Project Albert is an unclassified, international effort sponsored by the U.S. Marine Corps Combat Development Command (MCCDC) to apply ABM to combat modeling.[52] The Center for Naval Analyses (CNA) hosts two of the ABMs that have come out of this effort: EINSTein, a land combat ABM; and ISAAC, its cellular automata (CA) forerunner. ABM combat models are also being sponsored by non-U.S. governmental agencies, such as the New Zealand Defence Technology Agency (DTA) and the Defence Science and Technology Organization (DSTO) within Australia's Department of Defence. This work by New Zealand and Australian researchers is usually included in discussions about Project Albert. The Naval Postgraduate School in Monterrey, California is another source of research on ABM in military modeling. There are several master's theses published through the school that use military ABM models and discuss results. The U.S. Air Force (USAF) has also developed ABMs and has a literature on its usage.

This section of the chapter reviews the literature on ABM in military modeling. It begins with those pieces that are overviews or summaries of ABM in military applications and with those that are overviews of Project Albert. It then discusses work primarily aimed at describing specific land combat ABMs. After that is research that applies an ABM to a specific land combat problem and presents results. The last part of this section reviews work with ABMs on airpower questions. Overall, the literature on ABM in military modeling is very supportive of ABM's usefulness to combat simulations. Researchers argue that warfare is a complex adaptive system and that ABM research helps model non-linearities, co-evolving landscapes, and intangibles in a way not possible with previously available tools. It has been used to model a number of different combat-related aspects and appears to have the ability to advance understanding and inquiry in these areas. At the same time, non-combatants are absent from many (though not all) of the combat ABMs currently being developed. U.S.

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[51] Hill, Raymond, Gregory A. McIntyre, Thomas R. Tighe, and Richard Bullock. "Some Experiments with Agent-Based Combat Models," *Military Operations Research*, Vol. 8 (2000), no. 3, p. 17. (Henceforth referenced as Hill, et. al.)

[52] U.S. Marine Corps Combat Development Center (MCCDC), "Project Albert Description," accessed at http://www.mcwl.quantico.usmc.mil/divisions/albert/index.asp on April 1, 2004.

combat models in particular typically do not include unarmed or neutral agents that could be used to depict non-combatants.[53]

To begin with, there are pieces that serve as general discussions of ABM in military modeling. Ilachinski (1996) at the CNA was involved in ISAAC's development and discusses an "eight-tiered" approach to complexity and land warfare. Ilachniski begins with an introduction to complexity theory, non-linear dynamics, and complex adaptive systems. The author then discusses generic properties of a complex system and how they are relevant in land combat: nonlinear interaction, nonreductionism, hierarchical structure, decentralized control, self-organization, nonequilibrium order, adaptation, and collectivist dynamics. Ilachniski then reveals his "eight tiers of applicability" that complexity has for modeling land warfare: 1) general metaphors for complexity in war, 2) policy and general guidelines for strategy, 3) extending existing modeling approaches, 4) describing the complexity of combat, 5) combat technology enhancement, 6) combat aids for the battlefield, 7) developing synthetic combat environments for training, and 8) inspiring basic research and original conceptualizations of combat.

Horne (1999) discusses the main concepts behind Project Albert and the question of whether to confront an enemy directly or to maneuver. Horne uses the term "distillation" rather than model or simulation to refer to low-resolution ABMs and cellular automata models. This is terminology that is often echoed by other defense researchers.[54] Horne discusses the challenges facing someone attempting to answer the maneuver question through simulation: deterministic chaos, non-linearities, and intangibles such as cohesion, morale, and leadership. Arguing that current modeling approaches cannot cope with "complex, dynamic processes," the author describes Project Albert as a different approach to such analytical problems.

Holland, et. al. (1999) at Los Alamos National Laboratory discuss the concept of generative analysis. Rather than relying on analyst-dependent scenarios, the idea behind generative analysis is to explore a wider variety of conditions and scenarios. This is achieved by automatically generating different combinations of simulation factors. Using the example of a simulated urban

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[53] This is not to say that all non-combatants are always unarmed or neutral in a conflict. However, the majority of non-combatants typically are unarmed and are often not involved in coordinated military action with either the red team or the blue team.

[54] Calling models "agent-based distillations" appears to be unique to the military modeling community (both U.S. and non-U.S. researchers). Among some circles the term "multi-agent model" is also used. However, "agent-based model" seems to be the most widely used phrase for this class of simulation.

engagement, Holland, et. al. discuss how they would potentially generate millions of runs using less detailed models of different components. This would stand in contrast to a more standard modeling approach, which would have a few runs of more detailed models. If the objective is unconstrained exploration of the parameter space, some type of experimental design can be used to sample from the space. If the objective is to optimize a particular output, there are non-linear optimization approaches such as genetic algorithms or simulated annealing that may be used.

Upton (2001) is also an overview of Project Albert concepts and terminology. Upton calls generative analysis an "integrated technology" that depends on distributed computing, agent-based simulations, knowledge discover methods, and heuristic search techniques. Upton defines data farming – another Project Albert concept – as an interactive process between a human, a computer, an ABM, and techniques such as generative analysis. The paper illustrates how generative analysis might be applied by using the introduction of a new system, micro Unmanned Aerial Vehicles (UAVs), as an example.

Sanchez and Lucas (2002) describe ABM as a "cornerstone" of Project Albert because of the project's interest in intangibles in warfare but spend most of their discussion on the uses and strengths of the technique in general. Sanchez and Lucas review a few key characteristics of ABM and discuss analysis of ABMs. ABMs can be difficult to analyze because they differ from other classes of simulations. For example, there may never be a possibility of calibrating, predicting, or optimizing using ABMs. Sanchez and Lucas discuss considerations for implementing rules and collecting data. The authors also go over some methods for sampling from a space of all possible factor (full factorial) combinations: gridded, low resolution, group screening, frequency-based, and Latin Hypercube designs. Sanchez and Lucas also suggest visualizations that may be useful in understanding ABM results, such as regression trees, three-dimensional surface plots, Trellis plots, and contour plots.

Two 2002 *Information & Security* issues devoted to ABM use in defense and security provides a look at ABM research across a much broader number of issue areas than discussed within the Project Albert literature. The two issues cover agent-based defense modeling and simulation, the security of agent-based systems, coalition operations planning and negotiation, and agents in resource planning. The volumes also discuss using ABM to model situational assessment for submarines, air mobility planning, logistics planning, coordinating discovery of time-sensitive targets, planning for joint operations, threat assessment in small unit operations, military training, and robots in demining operations. An editorial in one of the issues also notes methodological and technical challenges for ABM in the field, including a lack of standard terminology, problems integrating ABM technology with existing large military simulations, the need for robust agent behavior controls, and the need to prove the usefulness and reliability of agents to the military. *Information & Security* argues that intelligent agents have been very effective in modeling military aspects that had not been modeled easily before, such as individual reasoning, communications, and coordination. Echoing many of the Project Albert authors, it also maintains that using agents to model combat as a CAS has shown insight into non-linearity, co-evolving landscapes, and intangible aspects of warfare.

Although the listing above shows the extent to which ABM may be applied to various defense and security issues, this literature review now turns to research involving ABMs that depict combat or military operations other than war (MOOTW).[55] Ilachinski (undated) discusses the cellular automata model, ISAAC (Irreducible Semi-Autonomous Adaptive Combat), and its ABM successor, EINSTein (Enhanced ISAAC Neural Simulation Toolkit). The author briefly reviews Lanchester Equations and contrasts the approach with ABM. Ilachinski again argues that land warfare contains the central features of a CAS, and that ABM allows understanding of emergent patterns when a system is not at equilibrium. ISAAC was created as a "proof of concept" to test to what extent warfare might be a self-organizing CAS. Ilachinski describes ISAAC agents, move selection, meta-rules, and sample behavior. He discusses the then-ongoing enhancement of ISAAC, EINSTein, and the ways in which EINSTein would expand on the former's capabilities. Two issues to be further explored with EINSTein are command and control and battlefield information. Ilachinski concludes by arguing that ABM not only offers a new general approach to modeling, but that it also causes researchers to invariably ask new and interesting questions. According to the author, ABM has the potential to aid discovery of fundamental new relationships between local and emergent phenomena in combat. ISAAC and EINSTein are "blue on red" "dot" models where the central focus is on interactions between combatants. However, non-combatants do not enter into either model.

Bailey (2001) discuses a model developed by the Defence Science and Technology Laboratories (DSTL) within the UK Ministry of Defence. DIAMOND (Diplomatic and Military Operations in a Non-warfighting Domain)

[55] In addition to these papers, there are user manuals and websites that showcase many of the ABMs. Although not all combat ABMs are available for public use, some are downloadable from the Internet. ISAAC and EINSTein are available at the CNA website. CROCADILE is also downloadable from the Australian Defence Force Academy's website. Although SEAS is not accessible without authorization, information about the model is available at www.teamseas.com.

was created to simulate peace support operations and models non-combatants and NGOs as well as military forces. DIAMOND is intended to answer force structure questions for peace support operations. Because the model was specifically created with these types of missions in mind, validation is based on past peacekeeping, humanitarian aid, and other similar operations. Bailey describes DIAMOND as a "high level, stochastic, object-oriented simulation" rather than as an ABM. However, entities within the model have information on their environment and make decisions about their activities. Interviews with researchers who have used DIAMOND also confirm that it is an ABM.[56] The model is constructed around nodes that represent physical locations such as cities, seaports, or other areas. There are facilities and information on functionality, damage, capacity, etc. There are four types of entities within the model: intervention forces, other factions, non-military organizations, and civilians. DIAMOND appears to have the most advanced simulation of non-combatants in any military simulation to date. The model can include up to several million civilians and attempts to include a range of behaviors. DIAMOND also allows for differing rules of engagement on the part of intervention forces.

Reynolds and Dixon (2001) briefly introduce Archimedes, another ABM to come out of Project Albert. According to the authors, Archimedes was designed to accept various missions including non-combatant evacuation operations (NEOs), other small scale contingencies (SSCs), and military operations on urban terrain (MOUT). Agents within the program can represent individual or units. Archimedes is also able to accommodate data farming and scalable fidelity. Agents have a physical state that represents their interaction with the physical world within the model as well as a behavioral state that represents intent. Agent rules may also be fuzzy, a feature that distinguishes it from other Project Albert ABMs. Reynolds and Dixon demonstrate Archimedes using a reconnaissance scenario.

Luscomb, Mitchard, and Gill (2002) at Australia's Defence Science and Techology Organization provide a brief introduction to MANA (Map Aware Non-uniform Automata), a cellular automata model developed by the New Zealand Defence Technology Agency (DTA). MANA was inspired by ongoing work in Project Albert and focuses on intangibles in combat behavior: cohesion, morale, fatigue, and suppression. MANA uses four states of behavior for its agents: unsuppressed, suppressed, pinned, and cowering. The intangibles affect

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[56] Phone interview with Chris Pernin at the RAND Corporation on the interviewee's experience with MANA, April 20, 2004, Santa Monica, CA.

the efficiency and effectiveness of agents in combat. Luscomb, Mitchard, and Gill emphasize MANA's contribution to furthering research on intangibles.

Grieger (2002) at Australia's Defence Science and Technology Organization (DSTO) gives an overview of several different ABMs and cellular automata models, referring to them collectively as agent-based distillations (ABDs). Grieger discusses ISAAC, EINSTein, MANA, Socrates, Archimedes/Pythagoras, and Bactowars. For each, Grieger discusses model parameters, data collection, terrain, and other features. Grieger also discusses differences between the models, including those in communication between agents, editing properties, parameters, data collection, run time, movement algorithms, interface, documentation, and numerous other aspects. Although not mentioned by Luscomb, Mitchard, and Gill, Grieger notes that MANA has neutral agents in the model whereas ISAAC and EINSTein do not. Grieger also discusses Socrates, another product of Project Albert. With three levels of command (grunts, commanders, and leaders), Socrates has a more detailed command structure than other land combat ABDs. Socrates also has no neutral agents and the model in general is noted as more difficult to use than other ABDs reviewed in the paper. Grieger also notes that Archimedes will be renamed Pythagoras in subsequent releases. The author also discusses how variables within Archimedes/Pythagoras can be fuzzy, allowing greater freedom when assigning behaviors but making it more difficult to implement. The paper also discusses Bactowars, an ABD in the early stages of development at the time of Grieger's writing. It is being developed by DSTO and is similar to ISAAC. In addition to reviewing ABDs, Grieger discusses agent movement algorithms in these types of models and conducts case studies using EINSTein and MANA.

Barlow and Easton (2002) discuss CROCADILE (Conceptual Research Oriented Combat Agent Distillation), and ABD developed at the Australian Defence Academy. The key features of CROCADILE include: a 3D or 2D environment; movement by air, land, or sea; command, mission, and communications structures for agents; higher fidelity combat resolution; multi-team structures; and neutral agents. Barlow and Easton review the simulation engine, agents, agent capabilities, and usage issues. The authors also run a traditional armored combat scenario 100 times and analyze results. Barlow and Easton argue that CROCADILE's contribution to the existing suite of Project Albert combat ABDs (ISAAC, EINSTein, MANA, etc.) is in: 1) adding greater model resolution, including a 3D environment; and 2) offering an extendible engine that can expand efficiently.

Schwarz (2004) discusses command and control for civilian actors in PAX, a German ABM that focuses on peace support operations. Funded by the German Bundeswehr's Training and Doctrine Command, PAX in another model associated with Project Albert. PAX stands out from most other Project Albert ABMs because its primary focus is modeling civilians rather than combatants. PAX models communication between military and civilian agents as well as communication among civilians.

Aside from these papers, there are research publications using Project Albert or other ABMs that captures military operations to test theories, explore relationships, and make recommendations. Lauren (1999) uses ISAAC to explore the basic behavior of CAS combat models. Lauren compares battle engagements between two forces of similar size first when forces attack forming Napoleonic squares, and then when forces use fluid formations. The author describes model statistics from the latter scenario as non-Gaussian and intermittent, with attrition rates that are the cube root of the kill probability rather than linear multiples as in conventional models. There is also a greater chance for extreme events under fluid formations. Lauren found that attrition was fairly constant over time when agents were deployed in squares. In contrast, when formation was fluid, battle was characterized by decisive clashes that could change the situation dramatically. Lauren also experimented with different types of agents, such as artillery, and found that adding agent types increased complexity.

Lauren and Stephens (2000) use ISAAC to model patrol survivability in a peacekeeping operation. The authors find that the main drivers of risk for peacekeeping troops are: enemy disposition, civilian disposition, the ability of enemy to support each other, and the ability of enemy forces to coordinate and concentrate. Lauren and Stephens maintain that in order to correctly gauge the risk that patrols face, friendly forces should understand enemy densities, training, and communication capabilities. They also find that opponents do not need to be very well armed in order to hamper peacekeeping missions. Also according to the authors, it is best if peacekeeping troops are considered too dangerous to challenge. Lauren and Stephen also very briefly mention Maui, another ABD being developed by the New Zealand Defence Operational Technology Support Establishment (DOTSE).

Brown (2000) uses ISAAC to investigate the human elements of command and control in an urban operation. Brown bases the modeling scenario on the United States Marine Corps's (USMC's) experience with withdrawing NATO troops from Somalia in 1995. The author also used a desert scenario. Brown models a smaller blue force against a larger, less technologically capable, and loosely organized red force. The author then covers

ISAAC parameters and the statistical methods used to evaluate model outputs. Brown measures time to mission completion and the number of blue forces killed during the course of a mission as measures of effectiveness (MOE). Increasing a local commander's information results in more maneuver and a longer time until mission completion. High sensor range also increased mission completion time dramatically and in a non-linear fashion. However, it did reduce the number of blue casualties. Brown also tests commanders' and subordinates' propensities to move towards other blue or red agents on the number of blue agents killed.

Woodaman (2000) applies ABM to military operations other than war, specifically to a confrontation between peacekeepers and a rioting crowd. The riot scenario is inspired by a 1994 incident between Cuban migrants and U.S. forces at Guantanomo Bay, Cuba. The author uses his own model AgentKit, an extension of Simkit. Peacekeepers in the scenario guard a site with nonlethal weapons as an initially peaceful crowd turns hostile and begins to throw stones. Woodaman uses two measures of effectiveness, expected hits taken per peacekeeper and expected hits taken per rioter. There are two tactical scenarios. In the first, peacekeepers are reactive and only return fire. In the second, peacekeepers are more proactive, firing on the most violent members of the mob, and attempting to break up the crowd. There are also two types of mobs: one with a clear leader and one without. According to Woodaman's simulation results, the proactive strategy results in fewer peacekeeper and rioter casualties. The presence of an explicit leader in the crowd did not make a significant difference.

Yiu, Gill, and Shi (2002) use MANA to model strategies for managing civil violence. The authors base their simulation of civil violence on the work by Epstein, Steinbruner, and Parker (2001) reviewed in the previous section of this chapter. Epstein, et. al. modeled "quiets" within the population transitioning to "active" and back. Some portion of agents active in civil violence become "jailed" and agents return from the jailed population as active. On the other hand, agents in Yiu, et. al. transition from quiets to actives to jailed and back to quiets. As in Epstein, et. al.'s model, "cops" within the population remove "actives" that they perceive. The authors investigate different strategies that cops and actives can implement. The optimal strategy for actives involves avoiding cops and mixing with the quiet population. The optimal strategy for "cops" is merely to concentrate on the actives instead of the general population. Yiu, et. al. also play optimal versus no strategy for both groups and discuss the results of each strategy combination.

Erlenbruch (2002) uses ABM to model peacekeeping exercises for German forces. The modeled exercise is from one used by at the German UN Training Center to train company and platoon leaders headed for Kosovo. Erlenbruch argues that peacekeeping operations are appropriately modeled as CAS. He uses two programs, Peacekeeping and TryShoot, to model tactics and training. Erlenbruch has red and blue agents, leaders and followers, and agent "personalities" that reflect risk aversion, closeness to leader, and other attributes. The measure of effectiveness is a combination of several utility functions that peacekeepers try to maximize. Peacekeeper utility is maximized when they minimize the following: access to the red objective, peacekeeper deaths, peacekeeper injuries, protester deaths, and protester injuries. From the results, Erlenbruch argues that using a defensive tactical approach resulted in the best MOE for peacekeepers. The author also argues that the value of using ABM to model peacekeeping is not in the answers but in the exercise of asking questions and learning the scenario.

Ling (2001) uses MANA to explore how uncertainty can hinder command and control operational effectiveness. Ling discusses the limitations of EBMs for understanding the dynamics of action and reaction in combat and in capturing intangible aspects such as emotions and team cohesion. He too argues for the applicability of CAS in modeling warfare. Within the scenario, red and blue agents attempt to capture one another's posts and to intercept opponent agents that come to capture theirs. Measures of effectiveness are time to reach the red post, number of blue casualties, and whether or not red agents capture the blue post. Ling focuses on two blue variables: the value of situational awareness and the number of squads. The number of blue squads is an attempt to introduce uncertainty for blue force command and control. Increased situational awareness was found to improve blue performance. Increasing the number of blue squads was found to add more complexity to agent behavior. As the number of squads increase, situational awareness appears to have a less clear impact on outcomes. Ling argues that MANA shows non-linearity and surprising behavior even with a simple command and control model.

Ghazal, Morley, Terry, and Klingaman (2003) use MANA to test three Soldier Tactical Mission System (STMS) alternatives for the U.S. Army (USA). These are current soldier, Land Warrior Version 1.0, and Objective Force Warrior. The authors briefly note the advantages of ABM and its "widespread use" by the USMC and USAF, as well as its widening use within the USA. The authors derived parameter values for current soldier and Land Warrior agents from field manuals and other DoD literature. Objective Force Warrior parameter came from Future Combat Systems (FCS) specifications as maintained by the

Defense Advanced Research Projects Agency (DARPA). Ghazal, et. al. varied parameters for firepower, fire range, communications delay, armor, and sensor range. Objective Force Warrior was superior to Land Warrior on all these parameter values and Land Warrior was superior to current soldier. The scenario was a squad-level encounter in a village. Ghazal, et. al. note that Land Warrior suffered fewer blue casualties and inflicted more red casualties than current soldier.[57]

In addition to land combat ABMs, there is also ongoing research sponsored by the USAF on modeling airpower through ABM. Tighe (1999) in his master's thesis at the Air Force Institute of Technology discusses applying ABM to analyzing the strategic effects of destroying key targets and centers of gravity. Tighe quantifies strategic effects through a method based on the Observe-Orient-Decide-Act (OODA) decision cycle. Although USAF theory and doctrine embrace the notion of strategic effects, Tighe argues that they are "not directly accounted for" in present military models and simulations. The author goes on to define strategic effects, noting that strategic attack should "produce effects well beyond the direct physical damage of the attack." Tighe then assesses THUNDER, a USAF theater-level combat model. He argues that THUNDER is not sufficiently able to model strategic effects and develops a proof-of-concept model that does incorporate strategic effects.

Bullock, McIntyre, and Hill (2000) at the Air Force Studies and Analyses Agency use an ABM, the Hierarchical Interactive Theater Model (HITM), to model the strategic effects of airpower. Each agent within the model has its own OODA loop, which can be examined for friction, or the dissipation of energy due to interactions with the opponent. The shorter the OODA loop, the less friction an agent is experiencing. Agents cause friction for their opponents by conducting air strikes against their opponents' centers of gravity. Red and blue teams within the simulation have equal amounts of territory and equal amounts of resources (centers of gravity). HITM provides for three different target sets: leadership (command and control), organic essentials, and infrastructure. There are also five classes of agents: commander, operations, ground units, defensive aircraft pilots, and attack aircraft pilots. Bullock, et. al. discuss three "regions" of non-linear systems: equilibrium, complexity, and chaos. The authors argue that their model results show these three regions. In model runs there is a "equilibrium" period where damage is local and results are stable. There is then

[57] Curiously, they do not note the simulation results for Objective Force Warrior agents. However, given the superior parameter values for Objective Force Warrior agents, it would be surprising if these agents did not have better simulation results than Land Warrior agents.

a "complexity" period where agents begin to adapt. This is then followed by a "chaos" period where damage propagates and destruction results. The model shows cascading effects from damage to centers of gravity that are consistent with the effects predicted by doctrine.

Hill, McIntyre, Tighe, and Bullock (2003) use HITM and a second prototype ABM, the Strategic Effects Model (SEM), to further investigate strategic effects from airpower. Hill, et. al. argue the case for applying CAS to combat and discuss the nature of agents in an ABM. The authors use SEM, a land warfare model partly inspired by ISAAC, to replicate the non-linear effects of information superiority as a force multiplier. The OODA loop is programmed into SEM agents as well and used to examine force multiplier effects. SEM is a "capture the flag" model that is primarily concerned with ground forces. Hill, et. al. compare Lanchester's square law results to model results to estimate the effects of force multipliers in SEM. The authors move to theater-level strategic effects by next running simulations in HITM, which extends land-based SEM to the theater level and adds an air component. The experiment is the one discussed in Bullock, McIntyre, and Hill (2000). The authors argue that HITM succeeds in capture the non-linear, cascading effects of destroying interdependent resources in a way not demonstrated by preceding models.

There are currently several agent-based military models in use. Table 2-1 below summarizes the ones mentioned above and notes whether or not they allow for neutral (non-combatant) agents. These models represent a body of knowledge about the uses and limitations of ABM in combat and MOOTW modeling. It represents a creative class of simulations that may be further enriched by the addition of non-combatant agents. Note that the U.S. Army does not currently sponsor an ABM, although perhaps it should. Additionally, most of the U.S. military ABMs that do exist do not incorporate non-combatants, even as the sheer scale of U.S. military activities mean that real-world interactions with civilians occurs on a frequent basis.

Table 2-1. Current Combat and MOOTW Cellular Automata and Agent-based Models

Model	Sponsor	Non-combatant Agents Possible
CROCADILE	Australian Defence Force Academy	Yes
Bractowars	Australian Defence Science and Techology Organization	N/A
DIAMOND	UK Defence Science and Technology Laboratories	Yes
EINSTein	Center for Naval Analysis; Office of Naval Research	No
HITM	Defense Modeling and Simulation Office; Air Force Studies and Analysis Agency	No
ISAAC	Center for Naval Analysis; Office of Naval Research	No
MANA	New Zealand Defense Technology Agency	Yes
Maui	New Zealand Defence Operational Technology Support Establishment	N/A
PAX	German Bundeswehr Training and Doctrine Command	Yes
Pythagoras/ Archimedes	USMC Combat Development Command	N/A
SEAS	USAF Space and Missile Systems Center Directorate of Transformation and Development	Yes
SEM	Defense Modeling and Simulation Office; Air Force Studies and Analysis Agency	No
Socrates	USMC Combat Development Command	No

Source: Bailey (2001), Barlow and Easton (2002), Grieger (2002), Hill, et. al. (2003), Lauren and Stephen (2000), Reynolds and Dixon (2001), www.teamseas.com, Schwarz (2004).

ISSAC and MANA are cellular automata models. Other may be: CA models and ABM are not always distinguished from each other in the ABD literature.

Applicability of ABM for Non-combatant Behavior

There are two main reasons for recommending ABM for non-combatant behavior in military models and simulations. First, ABM has already improved modeling in several areas that are closely related to non-combatant behavior during urban operations. The successful application of ABM in these areas makes it a logical extension to use ABM for many of the behaviors reviewed in this dissertation. Second, ABM offers the most practical solution for introducing large numbers of non-combatants into current military simulations. It appears to be the best alternative among several discussed below. And not inconsequentially, using ABM would permit researchers to salvage existing force-on-force models and expand their range of analysis into urban operations.

The first main reason for arguing in favor of using ABM is that it has already led to better models in areas relevant to non-combatant behavior during urban operations, such as crowd panic behavior, vehicular traffic, civil violence, and combat. ABM has produced good results when used to simulate certain types of human behavior; and at times, it has led to significant improvements over what was previously the standard method.[58] Simple and intuitive rules have been successful in capturing individual-level behavior not previously modeled well. In light of some of these developments, it is hardly novel to begin applying this technique to civilian movement and actions.

It should be clear that using ABM does not automatically produce a better model; it is susceptible to the drawbacks inherent in any modeling approach. As with any model, the output from an ABM is only as good as the assumptions that go into its construction. ABMs are as likely as other types of models to suffer from model artifacts, poor data, opaque assumptions, incorrectly specified relationships, researcher bias, insufficient sensitivity analysis, and incorrect application of model results. Additionally, a model that does not ask useful questions is of little use to decision makers regardless of the technique it uses. There are clear instances where ABM has not resulted in a model that is useful, and instances where the ABM model is not necessarily an improvement over existing forms of analysis.[59] However, in many instances it *has* led to better models and this point should not be overlooked. With the oft-repeated caveat that all models are wrong but some are useful, and the other major caveat that most models are to be used in conjunction with other forms of research and analysis, improved models should help lead to improved decision making.

Before further discussion on whether it is progress to use ABM for non-combatant behavior military models and simulations, it is necessary to first ask what constitutes a good model and what qualifies as an improvement. Clearly, whether or not a model is good depends on its purpose and the questions it is designed to help resolve: a simulation used to explain queues to students in an undergraduate operations research class is a good model if it illustrates the

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[58] Dirk Helbing, "Agent-based Simulation of Traffic Jams, Crowds, and Supply Networks," *Proceedings of the IMA 'Hot Topics' Workshop* (Minneapolis, MN: IMA, 2003), pp. 1-5.

[59] For example, it is not clear that Epstein, et. al.'s work with smallpox vaccination is a case where building an ABM gave results that were analytically sounder than or different from what could have been achieved with existing approaches. The primary conclusions that come directly out of that model are to focus on vaccinating health care workers and the family members of those that contract the disease. However, the ABM was not needed to arrive at this conclusion. Rather, the authors' results are largely driven by historic data which show that the highest smallpox transmission rates were in hospitals and in households. Casual observation of this information would also lead most informed analysts to identify hospitals and households as two areas to concentrate vaccinations. (One further criticism of the model is that if the high rate of smallpox transmission in hospitals was mostly the result of the disease spreading from patient to patient, vaccinating health care workers would not reduce most hospital-based transmissions.)

concepts effectively and a poor model if it does not get across the points that the instructor is trying to make. A high degree of technical sophistication does not automatically make a model good. For example, a military combat simulation designed to judge the potentially effectiveness of a certain weapon system may have a high degree of visual realism but still make for a poor model if there are significant oversights in combatant tactics.

ABM and Predictive Modeling

Although the definition of a "good" model may be quite case-specific, there are some general observations that may be made to gauge the quality of models. In general, models created to predict events or outcomes are judged on their predictive power; a change to a model is considered an improvement if it increases predictive power. Scientific and engineering models and simulations are good if they can accurately predict airflow over a wing design of certain proportions; predict the correct rate of gas exchange across a barrier; anticipate the directional stress load on composite materials; or forecast the correct blast effects from miniaturized nuclear weapons. The defense community uses many such technical models that are predictive in nature, particularly in research and development, where the mechanisms of a phenomenon are understood to a degree that researchers are able (to some extent) to substitute simulation for live experimentation.

ABMs have contributed to the art of predictive modeling in a few areas particularly relevant to non-combatant behavior in urban operations, such as crowd behavior. Prior to work by Helbing, Farkas, and Vicsek (2000), Still (2000), and Helbing (2003), most models of crowd flow in panic situations were based on the principles of fluid dynamics and particle systems: such models were consistent with previously help ideas in sociology that crowd participants were controlled by a collective crowd identity and lacked individually separate behavior.[60] However, fluid and particle behavior do not capture important aspect of crowd behavior, such as herding behavior, multi-directional flow, and uneven crowd density.[61] Such models are also no longer consistent with

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[60] Kincho Law, Kenneth Dauber, and Xiaoshan Pan, *Computational Modeling of Nonadaptive Crowd Behaviors for Egress Analysis: 2004-2005 CIFE Seed Project Report*, CIFE Technical Report #165, October 2005 (Center for Integrated Faculty Engineering, Stanford University, Stanford, CA 2005), p. 2. The authors consider work by Helbing, Farkas, and Vicsek to be consistent with fluid dynamics. However, this assessment is debatable given Helbing, et. al's agent-based approach and other features of their work which are clearly not consistent with fluid and particle behavior, such as dead individuals who block exits.

[61] Law, Dauber, and Pan, p. 6.

updated beliefs about the presence of individual behavior even within crowds. Additionally, fluid dynamics and particle systems are not ideal for modeling one important aspect of actual crowd panic situations, namely: individuals crushed to death who then become physical obstacles for others. The agent-based work in this area does constitute an improvement, and a significant one, because they result in models that more accurately predicted crowd movement, injuries, and deaths from panicked crowds.

ABM thus has a history in allowing researchers to improve modeling and simulation of this particular aspect of crowd behavior. There is also room for additional improvement in modeling crowds because the agent-based approach now allows for the construction of simulated crowds that demonstrate individually directed behavior. As more and more research points to this as the correct approach in describing crowd behavior (in contrast to the idea of individuals being uniformly directed by a collective), ABM offers a tool for simulations that better illustrate correct theories in this field. As dealing with crowds is a potentially dangerous part of urban operations, research and analysis on crowd dynamics should be of considerable interest to the defense community.

Traffic modeling is an area where ABM and cellular automata improved predictive power of traffic models because it is a technique that reflects individual behavioral rules that are consistent with the way drivers make decisions; and it produces system-level dynamics that reflect traffic real-world patterns. Until fairly recently, the dynamics of traffic jams were not easily recreated. In contrast to ABM and CA, top-down equation models of traffic primarily dealt with aggregate traffic statistics.[62] Such macro models were also often based on fluid dynamics or other models of movement from the physical sciences.[63] However, shortcomings of this approach included models that were extremely sensitive to initial settings, and models that depicted traffic only under ideal conditions.[64] The introduction of CA and then ABM in the 1990s in transportation simulation began a major shift towards models that took micro behavior into account.[65] Modeling self-directed agents with fairly simple rules for interactions have allowed researchers to recreate the dynamics behind stop-

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62 Peter Weiss, "Stop-and-Go Science," *Science News*, Vol. 156, No. 1, July 3, 1999, p. 8.

63 Kutluhan Erol, Renato Levy, and James Wentworth, *Application of Agent Technology to Traffic Simulation*, unpublished Department of Transportation technical report, 1999.

64 Erol, Levy, Wentworth.

65 Weiss, p. 8.

and-go traffic, "phantom" traffic jams, and other forms of vehicle congestion.[66] As a result, researchers are now able to use simulations to reasonably forecast the effects of speed limits, stop lights at on ramps, and other traffic control strategies.[67]

ABM has gradually become a standard approach to modeling traffic, one embraced by academics and graduate students with toy models as well as by government research centers funding major model development. TRANSIMS, an agent-based transportation network simulation of large metropolitan areas, illustrates how widely accepted ABM has become in this area. TRANSIMS was developed by Los Alamos National Laboratory with funding from the Department of Transportation (DoT), the Environmental Protection Agency (EPA), and the Department of Energy (DoE) as part of the Travel Model Improvement Program. Available from Los Alamos and from DoT, TRANSIMS is intended to assist regional transportation analysis of traffic congestion, energy consumption, land use, emergency evacuation, and other transportation issues.[68]

In light of these developments in transportation simulation and research, it hardly an untested or novel idea to use ABM to model civilian traffic in urban combat and MOOTW simulations. ABM has proven to be the best method to simulate traffic patterns from individual cars, and it would be illogical not to use it in the kind of high-resolution military models that depict individual combatants. It is clearly not possible to overlay an aggregate transportation model based on fluid dynamics onto an urban combat model and expect any realistic non-combatant reactions to combat. Modifications are doubtlessly necessary to the rules that govern vehicles in most ABM transportation models. For instance, TRANSIMS is unlikely to have agent rules specifying how drivers should react in the event they encounter gunfire, see other destroyed vehicles, find tanks in their path, experience an explosion in their vicinity, or receive communication that encourages them to abandon their trip. However, once reactions to these types of events are specified, agent-based vehicles should be able to give rise to traffic patterns, congestion, and other vehicle traffic considerations that could affect military operations.

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[66] Helbing, pp. 1-5.

[67] Helbing, p. 1.

[68] "Taking the 'Guessing' Out," TRANSIMS information page at Los Alamos National Laboratory's website; internet: accessed at www.ccs.lanl.gov/transims/index.shtml on January 21, 2006.

ABM and Exploratory Modeling

In addition to the contribution ABM has made to the types of predictive models discussed above, it has had a large impact on exploratory models that are relevant to non-combatants in urban operations. Combat and MOOTW models are rarely used in a predictive manner because of the highly complex nature of war. Instead, the purpose of large-scale warfare models such as JANUS and JCATS is largely exploration: exploration of tactics, configuration of forces, hypothetical weapons systems, and more. Exploratory use of models and simulations generates new avenues for further research by raising issues and relationships that may not have occurred to researchers without their use.[69] Exploratory models are also meant to be used *in conjunction* with other types of studies and analysis to further research and decision making on a topic. This is a "weak" use of models, but one that is as valid and as potentially useful as the "strong" use of predictive models.

How does one judge whether or not an exploratory model is good? It goes without saying that any model should produce results that are credible or at least plausible upon investigation. Results should also show internal consistency. Beyond this, the test of whether or not an exploratory model is good is not necessarily how complete it is, or even how "correct" the results are, but how many new ideas or insights it helps to generate. (A major improvement to exploratory modeling in generates additional insights of a significant nature.) When a phenomenon is being newly explored, almost any plausible exploratory model may be considered good because it helps to generate insights and points to avenues for further research that are also likely to be new.

Because ABMs currently being developed by the defense community allow researchers to investigate so many new phenomena that were difficult to embody using existing models, the community is almost in this precise situation. It is in the middle of a creative period where a new tool makes it relatively easy to construct new models exploring aspects of warfare excluded from previous models. There is no question that among the authors discussed in the previous section (ABM and Military Modeling), some analyses are better than others. However, ABMs have improved exploratory modeling in several topics pertinent to non-combatant behavior in urban operations: combat, peacekeeping, other MOOTW, civil disobedience, and crowd confrontation.

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[69] Phone conversation with Randall Steeb, January 6, 2006. Interviewee also discussed using models for comparing the performance of hypothetical weapons systems, and for exploring the implications of potential capabilities by paramaterizing the attributes of these systems.

A number of papers in the previous section demonstrated ABMs that are expanding the boundaries of exploratory military models. Ilachinski (undated) was among the first to explore the idea of combat as a self-organizing system. Luscomb, Mitchard, and Gill (2002) examine intangibles in combat behavior: unit cohesion, morale, fatigue, and suppression. Brown (2000) also used ABM to explore another intangible: human factors in command and control. ABM also allows Tighe (1999) and Hill, McIntyre, Tighe, and Bullock (2003) to demonstrate non-linearities from strategic effects that are consistent with military doctrine, but that were not previously captured in other models. Work in both the intangibles and strategic effects are in its early phases, but they represent new avenues of exploration and new elements that might eventually be introduced into mainstream, widely used combat simulations. The significance of the work listed above is not necessarily the particular results from these models, but their success in creating new insights and raising new questions. This successful use of ABM in exploratory combat models suggests that it could also yield new insights and new questions when used to incorporate non-combatants into combat models.

Even more directly relevant to evaluating ABM as an appropriate technique for non-combatants is the ABM work in MOOTW models that contain civilians. Lauren and Stephens (2000) use ABM to assess different risks for peacekeepers, including the effect of civilian disposition. Woodaman (2000) uses ABM to model a confrontation between peacekeepers and a rioting crowd. Bailey (2001) discusses modeling the interactions between military forces, non-combatants, and NGOs during peace operations. Yiu, Gill, and Shi (2002) model policing strategies for managing civil unrest and violence. Schwarz (2004) explores communication between civilian agents during peace support operations.

These works deal with such topics as civilian grievance, communication between civilians (and with combatants), and strategies for interacting with civilians to maintain order and to obtain intelligence and other forms of support. These are all important "intangibles" in U.S. military interactions with civilians, and there is a parallel to Project Albert work on intangibles in force-on-force combat. There are shortcomings to this body of work; mainly, they do not show deeper understanding of crowd behavior. Their non-combatant behavior does not seem to be based on any theory of crowd dynamics and only Woodaman appears to have used non-combatant behaviors from an actual historical event. However, it this body of research demonstrates a way to incorporate more complete research on these intangible non-combatant behaviors into military models using ABM. As ongoing events in Operation Iraqi Freedom show the overwhelmingly influence that these types of intangible and political factors can have on military operations,[70] there is a strong argument for attempting to include them in urban operations analysis.

ABM also has the potential to allow defense analysts to simulate non-physical aspects of non-combatant behavior. Currently, combat and MOOTW models include communication between combatants, but not between combatants and non-combatants, nor among non-combatants. Just as ABM has allowed modelers to begin exploring intangibles in combat, the technique better enables simulations to better handle aspects that current constructive and force-on-force models ignore. These include the impact of information operations on the local population; intelligence-gathering activities where combatants attempt to glean information from non-combatants; and changes in civilian attitudes over time. Ongoing events in Operation Iraqi Freedom have shown the importance of such intangible interactions with the civilian population, particularly in the context of counterinsurgency operations. Because ABM is an approach that is better than existing methods at allowing simulated individual to learn and communicate, it should be worthwhile to explore its application in this arena.

Practical Issues and Alternatives to ABM

The second major reason is that aside from the discussion above, there are significant practical reasons to use ABM to model non-combatants. In addition to illustrating non-combatants within purely ABMs, overlaying an ABM of non-combatants in existing accredited models would be a practical solution to expanding the range of these models to better cover urban operations. This would help salvage current, constructive, force-on-force models that have required vast amounts of time, money, and resources to build. Models such as Janus and JCATS are the result of significant development efforts. These models have also undergone a lengthy and detailed verification, validation, and accreditation process that is designed to improve the quality of widely used military simulations. Despite the effort that has gone into creating these existing large high-resolution combat models, they are ill equipped to handle many aspects of urban warfare. ABM is the best alternative if one wishes to salvage these models, and the following discussion examines its advantages and disadvantages relative to other modeling approaches that could also be used to add non-combatants to existing accredited models.

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[70] Thomas E. Ricks, "Lessons Learned in Iraq Show Up in Army Classes: Culture Shifts to Couterinsurgency," *Washington Post*, January 21, 2006, pp. A1, A9.

The discussion above has already discussed the advantages and disadvantages of ABM. There are other ways to represent non-combatant behavior in models and simulations: aggregate modeling, constructive modeling, and human-in-the-loop simulation. Looking at each of these in turn, each has limitations that make them more difficult to use than ABM for simulating non-combatants. For comparison's sake, this section also examines the strengths and weaknesses of using live actors to portray non-combatants in live exercises.

The first alternative approach, aggregate modeling, is by far the easiest to implement. This dissertation defines aggregate models to be those that do not deal with individual non-combatant actors, but use model inputs that represent aggregate numbers of non-combatants. An example of a simple aggregate model with non-combatants is an equation that uses the size of a city's population to suggest the number of troops required for peacekeeping or post-conflict operations. The advantage to aggregate modeling is that it is simple and not computationally intensive. Assumptions are usually much easier to discern than for other, more complex models. It is also trivial to "include" very large numbers of civilians. At the same time, this approach as significant drawbacks. Aggregate models of non-combatants miss much of the behavioral variation between individuals and do not illustrate the range of behaviors that troops on the ground might face. They are also good for a limited number of policy questions, such as force sizing and some civilian casualty estimates, but are insufficient for many other issues. For example, they do not allow models to incorporate individual-level behavioral theories and would not be useful for examining civilian crowds. They are unable to deal with localized phenomena or very complex non-combatant behavior. The also lack the resolution to serve as a test bed for such things as weapons or sensor technologies.

The second alternative is to use constructive modeling to control civilians in military models. Constructive modeling does allow for individual civilian actors and for different types of actors. However, actions are scripted, which does not allow for individual actors to react to their environment or surrounding actors. This tends to produce unrealistic behavior, such as civilians continuing to travel along their assigned paths even as combat erupts around them. Constructive modeling also makes it difficult to incorporate a large number of civilians into a simulation because programming individual and cooperative actions for each non-combatant becomes a time-consuming behavior. This makes constructive modeling difficult to scale to the population density level that would be seen in an actual urban environment.[71] It is possible to control large number of non-combatants in constructive models using statistical approaches. A 2004 Urban Resolve experiment modeled civilian vehicle traffic in Jakarta as part of a MOUT simulation. Individual civilians had a timetable of events, a randomly generated departure time within a particular window, and randomly generated routes.[72] Moving vehicular traffic is an important feature for MOUT models that include civilians, and the use of timetables does address the issue of scalability. However, non-combatants were still not able to react to combatants, one another, or their environment and behavior remained unrealistic. Because simulated non-combatants follow scripts, they would also be unable to show any of the complex behaviors discussed in this dissertation.

The third alternative is modeling with some HITL responses. HITL has the potential to generate non-combatant actors with a high degree of behavioral sophistication. No matter how adaptable ABM agents may be, humans "gaming" a simulation will always be able to display a wider variety of behaviors and advanced attributes such as learning, adaptation, communication, and deception. Human-controlled agents are also more flexible than programmed agents, making it easier to change the non-combatant environment. Showing complex non-combatant behavior is also easy with HITL. However, HITL approaches are also impractical to use for very large numbers of civilian actors. Behavioral rules for HITL actors may also be opaque, and non-combatant behavior is likely to vary considerably when the human in the loop changes.

The fourth alternative to using ABM (or any other purely virtual technique) is to depict non-combatants in live exercises. Using real human beings to act as non-combatants during an urban exercise has many of the same advantages that HITL simulations offer: very intelligent and adaptable civilians who can exhibit a range of behaviors. Theoretically, live exercises should be able to include a very large number of non-combatant actors. In practice, resource constraints, safety, and potential legal issues put limitations on the number of participants. They also limit the range of scenarios that one may consider because safety issues and resource constraints often limit the scope and variety of situations address in live exercises. One should also note that live exercises with civilian actors may be as susceptible to researcher bias as computer models. Controlling groups of exercise participants invariably involves giving them

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[71] E-mail correspondence with Randall Steeb at the RAND Corporation on ABM versus other modeling approach in military simulation. March 2, 2005, Santa Monica, CA.

[72] Ceranowicz and Torpey, pp. 3, 5.

instructions or guidelines for how to react and behave. Such instructions do establish the boundaries for behavior, suggest behaviors, define the level of hostility, and set many other characteristics for the live non-combatant population. These instructions will reflect the biases and assumptions of the person designing them, and it is unlikely that even live actors can ever act exactly as civilians do during actual urban operations.

Table 2-2 summarizes the advantages and disadvantages for ABM and the alternative approaches discussed above. The insufficiency of aggregate modeling for many policy issues and the impracticality of the remaining approaches almost leave ABM as the default method. ABM's disadvantages are manageable while its advantage of autonomous and scaleable agents addresses the prime shortcomings in constructive modeling. Scalability is also the key reason that ABM is a better choice than HITL modeling, and it is a factor in considering ABM over live exercises.

Table 2-2. Advantages and Disadvantages of Different Approaches to Replicating Non-combatant Behavior

Approach	Advantages	Disadvantages
Agent-based modeling	• Able to show individual-level behavior • Scalable • Heterogeneous actors • Learning and adaptation • Fairly simple agent behaviors give rise to complex non-combatant populations	• Non-combatant agents less intelligent or adaptable than HITL or live exercises • Use of technique does not automatically produce realistic behavior
Aggregate modeling	• Easy to implement • Sufficient for certain policy questions • Assumptions very transparent	• Unable to show individual-level behavior • Inappropriate for high-resolution modeling • Useful for limited number of policy applications • Unable to handle localized environments
Constructive modeling	• Able to show individual-level behavior • Heterogeneous actors	• Not easily scalable • Non-combatants do not respond to environment or other actors • Behaviors scripted and unlikely to be realistic • Complex population-level behaviors difficult to portray
Human-in-the-loop (HITL) during simulations	• Able to show individual-level behavior • Highly intelligent and adaptable civilian actors • Can easily exhibit broad range of behaviors • Complex population-level behaviors possible	• Not easily scalable • Behavioral rules not transparent • Non-combatant behaviors will vary with participants
Live exercises	• Able to show individual-level behavior • Simulated civilians intelligent and adaptable • Can easily exhibit broad range of behaviors • Complex population-level behaviors possible	• Narrower range of situations and scenarios • Resource constraints limit scalability • Potential safety and legal issues • Instructions given to participants also reflect designer biases and assumptions

Using ABM for non-combatants is also consistent with the current shift in military modeling towards autonomous combatants. One example of this trend is TacAir-Soar, an "entity-based" system that generates autonomous pilots in tactical air combat simulations.[73] Automated pilots are aware of their surroundings, are able to receive orders, and make decisions consistent with doctrine and tactics.[74] TacAir-Soar was an improvement over Semi-Automated Forces (SAFORs), a system that produced semi-autonomous tactical air agents but that still required human input for many aspects of their behavior.[75] Another example of the shift towards automation is MOUTbots, prototype autonomous adversaries developed specifically for urban training models. MOUTbots use Infiltration, a commercially available game, to model perception and motor actions. It also uses Soar cognitive architecture to model long-term memory, perception, situational awareness, mission information, and goals.[76] MOUTbots are intelligent, independent entities that can communicate and coordinate with each other. This method of using commercial game engines within the Soar architecture is already being applied in the OneSAF simulator, and other models such as Full Spectrum Warrior and Full Spectrum Command use similar algorithms.[77]

Autonomous, independent, and adaptive model entities such as those discussed above may be considered "agents". Although ABM quite often conjures images of dot models, the ABM literature also describes complex entities whose primary distinguishing trait is that they are autonomous and intelligent. There is no real separating line between the "entities" described in some of the more recent military simulations literature and the "agents" in some of the self-identified ABM literature. Thus in a sense, mainstream military modeling and simulation has already begun using agent-based approaches. It is incorrect to regard the Project Albert experiment in ABM as somehow unconnected to ongoing advances in more standard military simulations. Using ABM to introduce autonomous non-combatants into military models is new only in that the approach has not been widely used to date for non-combatant actors.

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[73] Randolf M. Jones, John E. Laird, Paul E. Nielsen, Karen J. Coulter, Patrick Kenny, and Frank K. Voss, "Automated Intelligent Agents for Combat Flight Simulation," *AI Magazine*, Vol. 20 (Spring 1999), pp. 27-8. Known henceforth as Jones, et. al.

[74] Robert E. Wray, John E. Laird, Andrew Nuxoll, Devvan Stokes, and Alex Kerfoot, *Synthetic Adversaries for Urban Combat* (American Association for Artificial Intelligence, 2004), p. 1. Known henceforth as Wray, et. al.

[75] Jones, et. al., p. 28.

[76] Wray, et. al., pp. 1-3.

[77] E-mail with Randall Steeb, March 2, 2005.

Because of all these properties listed above, ABM should be of obvious interest to anyone attempting to simulate non-combatants. Non-combatant behaviors contain many components that may be represented by a CAS. Non-combatants in urban operations are numerous, heterogeneous, operate on individual agendas, interact with other non-combatants, and respond to events around them. In contrast, current non-combatants in existing military models are usually unresponsive, homogeneous, and unable to interact with combatants. ABM's potential to simulate very different local non-combatant environments is also particularly relevant to urban operations. However, this is a feat that has not yet been achieved with non-combatants in existing models. ABM is also easily scalable to a large number of agents, allowing the possibility of simulating non-combatants in something approaching real-life population densities. Again, current military models and simulations lack realistic non-combatant population density. The ease with which ABM handles large populations suggests that further work with ABM may produce promising results.

The realistic densities of non-combatants, the individually driven and adaptive behavior, and the emergent population-level behavior that emerges also have the possibility of expanding an element in military simulations that is typically in short supply: the fog of war. Many things are meant by the fog of war, including: bad information, lack of information, poor communication, unexpected events, and other factors that produce cascading uncertainties. Some frequent criticisms of combat models are that actors are too rational and that there are too few uncertainties compared to real life warfare.[78] For those critics, having a virtual civilian population whose actions are not know beforehand (and whose interactions with combatants may have unforeseen consequences) should constitute an improvement over the current state of the art.

[78] Randall Steeb, phone conversation on purposes of military models and simulations, January 6, 2006, Santa Monica, CA.

3. Case Studies

This dissertation reviews three past urban campaigns: Operation Just Cause (Panama, 1989), UNOSOM II (Somalia, 1993), and Operation Iraqi Freedom (Iraq, 2003-ongoing). Case studies focused on non-combatant behavior, casualties, and interaction with combatants during urban operations. These behaviors are examined in greater depth in the following chapters. Cases were selected from recent and ongoing U.S. operations in urban terrain. All three cases involved high intensity urban warfare in the midst of sizeable urban populations. Panama and Iraq also included a post-conflict phase where non-combatants were prominent. The rest of the chapter discusses each of the case studies in turn and summarizes the non-combatant behaviors that came out of these case studies.

Operation Just Cause (Panama)

President George H.W. Bush ordered Operation Just Cause in 1989 with the primary aim of removing Panamanian leader General Manuel Noriega. The U.S. intervention came after steadily eroding relations between the United States and Panama. Tensions culminated in an incident on December 16, 1989 where Panamanian Defense Forces (PDF) killed a USMC lieutenant.[79] The operation began on December 20, 1989 and military action was largely over by December 24 when Noriega sought asylum at the Papal Nunciature.[80] U.S. Southern Command's (USSOUTHCOM) objectives were to destroy the combat capability of the PDF, to seize facilities vital to operating the Panama Canal, and to apprehend Noriega. Joint Task Force (JTF) South consisted of 13,000 U.S. troops already in Panama plus 9,500 additional personnel from the United States.[81] U.S. ground troops included Army infantry, airborne, and Rangers; Marines; and

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[79] Susan G. Horwitz, "Indications and Warning Factors," *Operation Just Cause: the U.S. Intervention in Panama*, edited by Bruce W. Watson and Peter G. Tsouras (Boulder, CO: Westview Press, 1991), pp. 56-7.

[80] Lorenzo Crowell, "The Anatomy of *Just Cause*: the Forces Involved, the Adequacy of Intelligence, and Its Success as a Joint Operation," *Operation Just Cause: the U.S. Intervention in Panama*, edited by Bruce W. Watson and Peter G. Tsouras (Boulder, CO: Westview Press, 1991), p. 67.

[81] Crowell, pp. 69-71.

Navy SEALS.[82] Panamanian forces consisted of 19,600 PDF personnel and 12,300 police, paramilitary, and Dignity Battalion members. Panamanian forces were equipped and organized to deal with internal security but not designed to face an invading army.[83]

U.S. forces carried out operations in and around Panama City and Colon, the two cities bordering the Panama Canal. Panama City had a population of 1.2 million while Colon had a population of 60,000.[84] Rules of engagement (ROE) allowed U.S. forces to shoot anyone that was armed, but U.S. personnel were also instructed to keep casualties – both combatant and non-combatant – to a minimum.[85] Approval was needed before ordering indirect fire from artillery or mortars, as well as for aerial bombing or strafing. (Gunship cannon and rocket fire were exempt.) Helicopter gunners were not permitted to return small arms fire from crowds and urban homes.[86] Additionally, U.S. personnel on the ground were not allowed to return fire from snipers operating from the midst of crowds.[87] Heavier weaponry, such as 90mm recoilless rifles, was not permitted against snipers on tenement balconies because of the hundreds of civilians within the buildings.[88] ROE were also designed to give members of the Panamanian armed forces an opportunity to surrender.[89] Many U.S. troops interpreted the ROE to mean that they had to take fire before being allowed to shoot.[90]

Some of the combat occurred in densely populated areas of Colon and Panama City where non-combatants were often intermixed with combatants. For example, some Panamanian military families lived in PDF buildings, and PDF complexes included civilian business or restaurants.[91] Inevitably, there were non-combatant casualties even with the ROE. Civilians were inadvertently

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[82] Ronald H. Cole, *Operation Just Cause: the Planning and Execution of Joint Operations in Panama* (Washington, DC: Joint History Office, Office of the Chairman of the Joint Chiefs of Staff, 1995), pp. 38-9.

[83] Crowell, pp. 69-71.

[84] Thomas Donnelly, Margaret Roth, and Caleb Baker, *Operation Just Cause: the Storming of Panama* (New York, NY: Lexington Books, 1991), pp. 234, 293.

[85] Donnelly, Roth, and Baker, p. 295.

[86] Crowell, p. 81.

[87] Melissa Healy, "Pentagon Puts Panama Civilian Deaths at 220," *Los Angeles Times*, January 10, 1990, p. 1.

[88] Malcolm McConnell, *Just Cause: the Real Story of America's High-Tech Invasion of Panama* (New York, NY: St. Martin's Press, 1991), p. 141.

[89] Crowell, p. 81.

[90] Healy, p. 1.

[91] Donnelly, Roth, and Baker, pp. 177, 249-50.

injured and killed inside their homes or as they fled gunfire. There were also incidents of people in civilian vehicles being killed at roadblocks.[92] Additionally, there were an uncertain number of deaths from the fires that started during the fighting. On the first night of Operation Just Cause, fires broke out among several wooden buildings surrounding PDF headquarters in the El Chorillo neighborhood of Colon.[93] U.S. tracer rounds are thought to be responsible for some of these fires.[94] And estimated 2,000 buildings were burned down,[95] leaving about 2,700 families in El Chorillo (between 10,000 and 15,000 people) homeless.[96] However, civilians in Colon were generally friendly to U.S. forces and reacted with celebration at the news that Noriega had surrendered.[97]

After initial combat in Colon, U.S. forces were engaged in negotiations to convince remaining PDF forces to surrender. Snipers, often members of the Dignity Battalion, operated from civilian buildings and crowds in Colon and Panama City after PDF forces had largely stopped fighting. Snipers continued even after Noriega was in U.S. custody.[98] In the meantime, Colon residents began looting the city. Navy SEALs killed three armed civilians during looting in Colon in an incident that reduced the scale and magnitude of the looting afterwards.[99] Tear gas was also somehow released within the city, causing some to panic. U.S. forces urged civilians to remain in their homes, but some 200 out of the 60,000 living in Colon fled the city. Looters ransacked hundreds of stores and looting continued even though U.S. forces were in control of Colon by the third day of the invasion. There was also extensive looting in Panama City.[100] In that city, U.S. military operations largely took place on the outskirts of the city. However, looting began in the center of the capital early on December 20th. Looting and chaos continued in downtown Panama City for three or four days and firefights often broke out between vigilantes, looters, and Dignity Battalion forces.[101] It should be noted that looting in Panama City began on December 20,

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92 Kevin Buckley, *Panama: the Whole Story* (New York: Simon & Schuster, 1991), p. 265.

93 "El Chorrillo Two Years After the U.S. Invaded Panama, Those Displaced by the War Have New Homes – But are Less Than Satisfied with Them," *Christian Science Monitor*, December 20, 1991.

94 Crowell, p. 86.

95 Buckley, p. 240.

96 "El Chorrillo Two Years After the U.S. Invaded Panama"; Buckley, p. 240; and Donnelly, Roth, and Baker, p. 381.

97 Donnelly, Roth, and Baker, p. 312.

98 Donnelly, Roth, and Baker, p. 313; and Watson and Tsouras, p. 93.

99 McConnell, p. 237.

100 Donnelly, Roth, andBaker, pp. 267, 292-3, 304.

101 John T. Fishel, *Civil Military Operations in the New World* (Westport, CT: Praeger, 1997), p. 58.

the same day that Operation Just Cause began. It appears that looting began as soon as it became clear that Noriega's forces were no longer in control, even though Noriega did not officially surrender until four days later.

Estimates of the total number of non-combatant dead are better for Panama than they are for the other two cases in this dissertation. The most credible estimates of Panamanian civilian deaths during Operation Just Cause put the number between 200 and 300. USSOUTHCOM estimated 202 civilians and 314 Panamanian military dead, while the Panamanian Institute of Legal Medicine estimated 270-345 Panamanian civilian and military dead.[102] The independent Panamanian Committee for Human Rights calculated 565 total Panamanian deaths, and the U.S. Physicians for Human Rights came up with a comparable figure.[103] The Panamanian Institute of Legal Medicine and the Panamanian Committee for Human Rights identified 13% of the dead as women and children.[104] Operation Just Cause also saw one U.S. civilian death.

Overall, despite the civilian casualties and the overthrow of a Panamanian government, Panamanians were basically friendly to U.S. forces. Panamanians had historically been concerned about the extent of U.S. influence in Panamanian affairs. However, the Noriega government was unpopular and Panamanian public opinion generally favored the U.S. invasion.[105] During combat between U.S. and Panamanian forces, civilians ran from gunfire and did not attempt to interfere. (This is in contrast to civilians in Mogadishu, as will be described below.) There was no attempt on their part to act as human shields for Panamanian forces or to attack U.S. forces. Civilians even went as far as to identify PDF members and armed civilians for U.S. troops after Noriega surrendered.[106] Panamanian forces were generally in uniform and did not attempt to use civilians as human shields. Although some Dignity Battalion members did operate out of crowds and civilian buildings, this behavior did not seem to be as extensive as it would later be in Iraq. Panamanian forces did use

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[102] McConnell, p. 262. Claims of several thousand dead Panamanian non-combatants were found to be unsubstantiated by subsequent Panamanian and U.S. government investigations.

[103] Kenneth Freed, "Invasion Ghosts: Panama Tries to Bury Rumors of Mass Graves; Allegations Persist That up to 4,000 Civilians were Killed in the U.S. Invasion," *Los Angeles Times*, October 27, 1990, p. 3.

[104] United States House of Representatives, Committee on Armed Services, Investigations Subcommittee, *The Invasion of Panama: How Many Innocent Bystanders Perished?* Report of the Investigations Subcommittee. 102nd Congress, Second Session, July 7, 1992 (Washington, DC: U.S. Government Printing Office, 1992), p. 5.

[105] Buckley, p. 250.

[106] Donnelly, Roth, and Baker, p. 304.

civilian buses and other vehicles, but did not appear to do so out of any deliberate effort to camouflage themselves among the civilian population.

Operation Continue Hope (Somalia)

In 1992 and 1993, the UN undertook humanitarian relief efforts to address a famine in Somalia and peacekeeping operations to broker a ceasefire in that country's civil war. UN Operations in Somalia (UNOSOM) lasted from April 1992 to March 1993. (Operation Provide Relief and Operation Restore Hope were the U.S. contributions to UNOSOM I.[107]) Under UNOSOM I, UN peacekeepers were to observe a ceasefire between warring factions in Somalia and to escort humanitarian aid deliveries in Mogadishu and other areas of the country.[108] However, the security situation continued to worsen. When it extended UN operations after the end of UNOSOM I, the UN Security Council authorized the 22,000 peacekeeping troops involved in UNOSOM II to use force if necessary to provide for a secure environment for ongoing humanitarian aid. (Operation Continue Hope was the U.S. contribution to UNOSOM II.) UNOSOM II continued from March 1993 to March 1995.[109] Unfortunately, the ceasefire did not hold during UNOSOM II either. In June, fighting between armed Somalis and UNOSOM II personnel in Mogadishu left two dozen Pakistani peacekeepers dead. Other clashes between UN peacekeepers and Somalis followed. Then in October 1993, 18 U.S. peacekeepers died during a raid on members of Mohamed Farrah Aidid's Habr Gidr clan in Mogadishu. The United States withdrew from Somalia in early 1994. UNOSOM II continued after the withdrawal of U.S. troops and formally ended in March 1995.[110]

Most of this discussion about non-combatants in Operation Continue Hope centers around the two-day U.S. raid on October 3-4, 1993. Task Force Ranger's objective during a midday raid on the 3rd was to arrest several of Aidid's top aids, including his foreign minister, political advisor, and propaganda chief.[111] Members of Task Force Ranger included Army Rangers,

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[107] Kenneth Allard, *Somalia Operations: Lessons Learned* (Washington, DC: National Defense University Press, 1995), p. 15.

[108] United Nations, "United Nations Operations in Somalia, I," Internet: accessed at http://www.un.org/depts/dpko/dpko/co_mission/unosomi.htm on October 13, 2004.

[109] "UNITAF" stands for United Task Force and referred to the body of peacekeeping troops involved in the UNOSOM operations. UNITAF does not denote another UN operation.

[110] United Nations, "Somalia – UNOSOM II, Background, Summary," Internet: accessed at http://www.un.org/Depts/dpko/dpko/co_mission/unosom2backgr1.html on July 1, 2004.

[111] Bowden, pp. 3-4; and Ed Wheeler and Craig Roberts, *Doorway to Hell: Disaster in Somalia* (Tulsa, OK: Consolidated Press, 2002), pp. 4-5.

Delta Force, and Navy SEALs. It was composed of 19 aircraft, 12 ground vehicles, and about 160 men.[112] U.S. troops faced Aidid's Somali National Alliance (SNA) militia plus other irregular fighters who joined in the fighting. Although the UN estimated the militia's strength at about 1,000 full-time members, the SNA claimed 12,000 militia members.[113] UN ROE in place at the time allowed UN peacekeepers to engage technicals, militia, and other armed crews without provocation. U.S. forces had a more aggressive interpretation of the ROE than other peacekeepers.[114]

During the October raid in Mogadishu, there were several types of participants. Aside from U.S. troops, there were members of Aidid's militia, other armed Somalis who fired at the Americans, non-combatants who assisted those opposing U.S. forces, and other non-combatants not directly involved in the fighting.[115] While civilians in Panama on the whole had been reasonably friendly to U.S. forces, Somali civilians proved to be quite hostile to U.S. troops. For example, by one estimate, there were three or four non-militia Somalis shooting at the Americans for every militia member also in the fight.[116] By another estimate, there were some 50,000 people loyal to Aidid in the Wardigley district of Mogadishu where the raid took place.[117] Citywide, estimates of Mogadishu's total population ranged from half a million to nearly a million in 1995.[118]

Unlike in Panama, civilians in Somalia often actively attempted to interfere with U.S. military operations during the October raid. In the initial phase of that operation, thousands of Somalis (many armed) ran into the streets towards U.S. forces. Overhead videotape of the engagement also showed "crowds of Somalis throughout the area erecting barricades and lighting tires to summon help," presumably from Aidid's militia or from irregular fighters.[119]

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112 Bowden, pp. 5-6.

113 Rich Atkinson, "The Raid that Went Wrong; How an Elite U.S. Force Failed in Somalia," *Washington Post*, January 30, 1994, p. A1.

114 Allard, p. 37.

115 Rick Atkinson, "Night of a Thousand Casualties; Battle Triggered U.S. Decision to Withdraw from Somalia," *Washington Post*, January 31, 1994, p. A1.

116 Bowden, p. 200.

117 Wheeler and Roberts, p. 5. It is not clear how many of these 50,000 engaged in armed or unarmed opposition to U.S. forces.

118 "Mogadishu," *Tiscali Reference*, 2004, Internet: accessed at http://www.tiscali.co.uk/reference/encyclopaedia/hutchinson/m0002385.html on July 29, 2004; and "Somalia Page," *ElectionsInfo.com*, 2003, Internet: accessed at http://www.electionsinfo.com/coun/s/somalia/index.php on July 29, 2004.

119 Bowden, p. 19.

This behavior of civilians running towards the sound of fighting is a very unusual civilian response to combat. Some have explained this as cultural. However, in addition to any cultural differences, there appear to have been other factors that could have encouraged less timid civilian behavior than in the other case studies. One is that neither Noriega's or Saddam Hussein's government had popular backing. Somalia did not have and still does not have a functioning government to speak of. However, Aidid's control over parts of Somalia was based on clan loyalties that gave him the support of many Somalis who were also members of the Habr Gidr clan. Another potential factor was the scale of the conflict in Mogadishu compared with the other case study cities. Fighting in Mogadishu involved a small number of U.S. troops in HMMWVs, trucks, and helicopters. In contrast, fighting in Baghdad and other Iraqi cities involved much larger U.S. forces with Abrams tanks and a "shock and awe" aerial campaign. Fighting in Panama also involved a greater use of force than in Somalia.

For several reasons, the distinction between non-combatants and combatants was especially difficult to make in Mogadishu. First, Somali militiamen and other armed Somalis did not have uniforms. Just as combatants in Somalia were distinguishable only by the arms they were carrying, militia vehicles were also armed civilian vehicles. Aidid's militia did not have vehicles that would normally be considered military vehicles. However, Aidid's men rode around in "technicals" – trucks armed with machine guns. Second, there was an unusual amount of intermixing between combatants and non-combatants. In Mogadishu, gunfire brought Somalis both running towards it and away from it. A crowd would often gather at the site of a firefight ten to twenty minutes after it began. People flocking to the sound of gunfire included women, children, and the elderly in addition to armed Somali men.[120]

Third, people who would traditionally be considered non-combatants often joined in the fighting. For example, in one incident a Somali boy about five years old fired an AK-47 at U.S. troops. In another incident, a woman held a baby as she fired her pistol at U.S. forces.[121] Fourth, unarmed non-combatants often voluntarily acted as human shields. Somali women and children stood in front of armed combatants, both during the October 1993 raid where 18 U.S. servicemen died and during the June incident when the Pakistani peacekeepers

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[120] Bowden, pp. 20, 35, 169.

[121] Bowden, pp. 128, 157. U.S. troops shot both the boy and the woman in response.

were killed.[122] On the other hand, it also seems that concerns about civilian casualties may also have encouraged Somali combatants to exercise restraint. In an interesting twist on the usual debate about human shields, many Somalis claim that U.S. troops avoided being killed as they spent the night of October 3rd in the city because they took women and children hostages.[123]

Overall Somali civilian attitudes towards U.S. troops were quite hostile. Somali combatants mobilized the population with megaphones, calling them to come out and defend their homes. The U.S. presence also seemed to unify and galvanize the various armed groups within the city.[124] In contrast to operations in Panama, where civilians provided U.S. personnel with intelligence, civilians in Operation Continue Hope identified U.S. positions to Somali gunmen.[125]

Civilians in Operation Just Cause did not have a significant impact on either the outcome of U.S. military operations or the magnitude of U.S. military casualties. In contrast, civilians in Mogadishu increased the mission's difficulty for U.S. troops. Somali leaders are quoted as saying that they had 312 killed and 814 wounded.[126] However, it is unknown how many of this number were militia, how many were irregular fighters who joined in the action, or how many were genuine non-combatants. Other sources put the number of Somali civilian deaths at over 500.[127]

Operation Iraqi Freedom (Iraq)

The United States launched Operation Iraqi Freedom (OIF) in March 2003 primarily to prevent the use of Iraq's suspected weapons of mass destruction against the United States. British, Australian, and Canadian forces

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122 United States House of Representatives, Committee on Foreign Affairs, Subcommittee on Africa, *Recent Developments in Somalia*. Hearing before the Subcommittee on Africa, 103rd Congress, First Session, July 29, 1993 (Washington, DC: U.S. Government Printing Office, 1994), p. 45.

123 Atkinson, "The Raid that Went Wrong," p. A1. U.S. troops occupied four homes on Freedom Road on the night of October 3rd and held the inhabitants inside as well. According to U.S. commanders, this was done out of concerns that the inhabitants could be killed in the crossfire; that they could give away U.S. strength and locations; and that they could have joined the Somalis already fighting U.S. troops. There is no indication that a desire to discourage Somali fire prompted U.S. forces to detain the civilians inside the homes.

124 Sean J.A. Edwards, *Swarming and the Future of Warfare* (Santa Monica, CA: RAND Corporation, Pardee RAND Graduate School dissertation), p. 265.

125 Edwards, *Swarming and the Future of Warfare*, p. 266.

126 Atkinson, "Night of a Thousand Casualties," p. A1.

127 Russ Glenn, Randall Steeb, John Matsumura, Sean Edwards, Robert Everson, Scott Gerwehr, John Gordon, *Denying the Widowmaker: Summary of Proceedings of the RAND-DBBL Conference on Military Operations on Urbanized Terrain* (Santa Monica, CA: RAND Corporation, 2000), p. 6. Henceforth referred to as Glenn, et. al.

also participated in OIF. In total, the invasion of Iraq involved almost 470,000 U.S. and coalition personnel, of which approximately 170,000 entered Iraq.[128] OIF may be thought of in two major phases: major combat operations and post-conflict operations. Major combat operations lasted from March 19, 2003 to May 1, 2003. The second major phase of OIF lasted through the handover of sovereignty back to an Iraqi government in June 2004 and was ongoing at the time of this dissertation. In November 2003, there were about 140,000 U.S. and coalition forces in Iraq.[129] Although Iraqi civilians had ample warning of impending hostilities, OIF did not trigger the wave of refugees feared by many humanitarian aid agencies. Instead, the vast majority of non-combatants remained in their homes and was present during major combat operations. Although Iraqis left local areas that experienced fighting during the post-conflict operations, the second phase of OIF did not appear to generate large numbers of displaced persons either.

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[128] T. Michael Moseley, *Operation Iraqi Freedom – By the Numbers* (Assessment and Analysis Division, U.S. Central Command Air Forces, 2003), p. 3; and Franks with McConnell, p. 434.

[129] Andy Oppenheimer, "Iraq: Current Developments and Recent Operations," *Jane's World Armies*, June 21, 2004, accessed through online Jane's database.

Figure 3-1. Aerial Photograph of Baghdad (April 2, 2003)

Source: NASA.

Unlike the 1991 Gulf War, a significant percentage of the fighting during major combat operations in OIF took place in urban areas. Fighting occurred in cities such as Baghdad, Basra, Nasiriyah, and Najaf.[130] Baghdad was Iraq's

130 David Zucchino, *Thunder Run, the Armored Strike to Capture Baghdad* (New York: Atlantic Monthly Press, 2004), p. 3.

largest city, with an estimated 5.6 million inhabitants.[131] During this stage of OIF, U.S. forces faced the regular Iraqi Army, Iraqi Republican Guard, the paramilitary Saddam Fedayeen, and irregular volunteers from other Arab countries. Rules of engagement for the U.S.Army's Third Infantry Division (ID) allowed soldiers to shoot anyone in uniform or anyone with a weapon. While many of the Iraqi soldiers and Republican Guard were in uniform, some were in civilian clothing and some wore mixed civilian and military clothing. Fedayeen dressed in black or in civilian clothes. Adding to the confusion were armed combatants deliberately dressed as civilians and soldiers shedding both their arms and their uniforms.[132] There were also reports of gunmen in civilian clothing pretending to surrender or pretending to be dead.[133]

In Baghdad the Fedayeen did much of the fighting while Iraq's conventional forces were not as active in engaging U.S. forces. During major combat operations in OIF, the Fedayeen disguised themselves as civilians and operated from civilian buildings and vehicles.[134] Iraqi conventional forces also appeared to have a strategy of putting military equipment and munitions in populated areas. One U.S. Army battalion commander remarked that the Iraqi military and Fedayeen had put "90%" of their munitions caches in hospitals, schools, and mosques.[135] Fedayeen also used Iraqi civilians as human shields in a much more direct way. In villages in southern Iraq, Fedayeen forced groups of civilian outdoors to act as shields. They also held women and children inside buildings from which they fired at U.S. troops.[136] Human rights agencies reported frequent instances of Fedayeen deliberately using individuals and Iraqi families to attempt to shield themselves when confronted by U.S. forces.[137] Eyewitness accounts give specific examples where Fedayeen deliberately sought out women and children as shields.[138] Foreign Arab volunteers also often operated with a similar attitude towards civilians as the Fedayeen.[139] Iraqi

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[131] CIA population density map of Baghdad, 2003, internet: accessed at http://www.lib.utexas.edu/maps/middle_east_and_asia/iraq_pop_2003.jpg on August 2, 2004.

[132] Dexter Filkins, "A Nation at War: In the Field Choosing Targets; Iraqi Fighters or Civilians? Hard Decisions for Copters," *New York Times*, March 31, 2003, p. B5.

[133] Zucchino, p. 32.

[134] Interview with Bruce Pirnie on combat operations during OIF, March 10, 2004, Arlington, VA.

[135] Human Rights Watch, *Off Target: the Conduct of the War and Civilian Casualties in Iraq* (United States: Human Rights Watch, 2003), pp. 74-5, 119.

[136] West and Smith, pp. 64, 74.

[137] Human Rights Watch, p. 67.

[138] Human Rights Watch, pp. 67-8.

[139] Zucchino, p. 110.

civilians generally did not attempt to interfere in the fighting or to actively aid Iraqi combatants as Somali civilians had done. Although Iraqi combatants deliberately attempted to disguise themselves within the surrounding civilian population, in general Iraqi civilians were not active participants in this tactic. Instead, civilians appeared to be reluctant involuntary human shields.

Iraqi civilians did seek shelter during the fighting and generally appeared to be taking defensive actions. However, there were occasions during major combat operations when they seemed to misunderstand their immediate danger. For example, in one case civilians remained standing as U.S. Marines shot at snipers in their midst. In that particular incident, civilians evidently had a high degree of faith in the accuracy of U.S. weapons and the ability of U.S. troops to shoot whomever they wanted without harming bystanders.[140] This misunderstanding of U.S. technology may also have been a factor in why so few Iraqis left Baghdad before OIF began.[141]

During OIF, there was also frequent intermingling of non-combatant and combatant vehicles. One reason for this intermixing was that Iraqi combatants deliberately attempted to use civilian vehicles for cover. The Fedayeen often used civilian vehicles during major combat operations in Baghdad. In addition to employing civilian trucks mounted with machine guns or anti-tank weapons, Iraqi combatants fired weapons out of cars that were otherwise indistinguishable from civilian vehicles. Iraqi combatants also attempted to drive close to U.S. vehicles with hidden anti-tank and other weapons, posing as civilians. Additionally, Fedayeen deliberately forced civilians into Fedayeen vehicles in an attempt to use them as human shields.[142]

One feature present during the battle for Baghdad (but not in Colon, Panama City, or Mogadishu) was the presence of suicide bombers in civilian vehicles attempting to approach U.S. forces.[143] This considerably heightened tensions for U.S. troops over seemingly civilian vehicles that could have hostile intentions.[144] It had an effect on how U.S. forces tended to perceive approaching civilian vehicles, even though the actual number of suicide bombers turned out

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[140] West and Smith, p. 96. Although it is difficult to say for sure, this faith in U.S. technology might also have been a factor in why Iraqis remained in Baghdad even during the “shock and awe” aerial bombing campaign.

[141] Other likely factors include the stores of rations that Iraqis had been issued in the months and weeks preceding the war.

[142] Human Rights Watch, p. 68.

[143] Zucchino, pp. 26-7.

[144] Zucchino, pp. 26-7.

to be fairly low. (One former USMC officer that accompanied the 1st Marine Division into Baghdad estimated that one out of perhaps ten thousand cars approaching U.S. forces was a suicide bomber.[145]) For approaching vehicles, ROE for units of the U.S. Army's 3rd ID instructed them to fire a warning shot and then to fire into the engine before firing at occupants.[146] By some accounts, however, there were no clear instructions for when to fire on approaching vehicles for the 1st Marine Division that was also sent into Baghdad.[147]

A second factor that added to this intermingling of vehicles was the fact that Iraqi civilians also seemed to underestimate the dangers of driving during combat. On the approach to Baghdad, U.S. forces often encountered civilians driving on highways at night. This was despite the fact that civilians were evidently aware that U.S. tanks and Fedayeen in civilian vehicles were also on the road.[148] Iraqi civilians for their part did not seem to grasp the danger they were in because of the Fedayeen's tactics and continued to drive in plain sight of American forces. Civilians seemed to fail to understand the level of danger they faced when they were near U.S. forces and inadvertently provided cover for Iraqi combatants. (There is no evidence to suggest that civilians purposely drove on the streets to camouflage the Fedayeen.) They also seemed to disregard the additional difficulty that U.S. forces would have in distinguishing between vehicles at night, regardless of night-vision technology.

A third factor that increased the number of non-combatant vehicles on the battlefield was a lack of information. When U.S. troops began the battle for Baghdad, the vast majority of Iraqis were not aware that the Americans had entered the city. Instead, they were driving around the city carrying on their normal activities. With Saddam Hussein's government announcing to its public that U.S. forces had been stopped outside the capital, even members of his armed forces were caught off-guard when they came face-to-face with U.S. combat vehicles in the city.[149] Many Iraqi families continued routine travel on Baghdad's roads and highways during the initial U.S. advance into the capital, often blundering into crossfire or straight at U.S. military vehicles. Even when U.S. forces followed ROE designed to warn off approaching vehicles, many civilians killed in approaching vehicles appeared to have ignored or

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[145] West and Smith, p. 67.

[146] Zucchino, pp. 10, 13, 16.

[147] Bing West and Ray L. Smith, *The March Up: Taking Baghdad with the 1st Marine Division* (New York, NY: Bantam Books, 2003), p. 63.

[148] West and Smith, p. 65.

[149] Zucchino, pp. 34-5.

misunderstood these warnings.[150] In some cases, civilians who were killed by U.S. troops for driving towards them did not seem to have heard warning shots or to even notice U.S. tanks before they were shot.[151]

Although non-combatants did not play an active role in events at the beginning of OIF, large numbers of Iraqis did participate in the looting that followed the fall of Saddam Hussein's government. Iraqi civilians began looting government buildings and state-owned companies on the same day as soon as it became clear that the government was no longer in control.[152] Just as Panamanian looters did not wait for Noriega to surrender before they began taking advantage of the lack of law and order, Iraqi looters were also opportunistic and began looting the same day it was clear that Saddam Hussein was no longer in control. (U.S. forces later captured Saddam Hussein on December 14, 2003.[153]) The looting increased in scope as it continued for days and in many cases turned violent.[154] Looting was also reported in other cities such as Basra and Mosul, even though Mosul had not seen any previous fighting during OIF.[155] Baghdad descended into lawlessness and chaos with few Iraqis deterred by the relatively small number of U.S. troops present in the city at the time. Scenes of civilians looting for days in Baghdad and other Iraqi cities created political pressure for the U.S. government to bring the situation under control quickly. At the operational level, there was pressure for U.S. troops to transition into law enforcement activities, even as they continued to conduct combat operations against remaining combatants.

Total Iraqi civilian casualties during major combat operations are difficult to estimate. While there are better figures available than for Operation Restore Hope, estimates of the number of non-combatants killed are not nearly as precise as they were for Operation Just Cause. The Project on Defense Alternatives estimated that 8,789 to 10,638 civilians died between March 19, 2003 when the war started and March 31, 2003. The group's estimate was based on

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[150] Zucchino, pp. 141-2.

[151] Zucchino, pp. 35, 142.

[152] Anthony Shadid, "Hussein's Baghdad Falls," *Washington Post*, April 10, 2003, p. A1; and "Looting Breaks Out in Baghdad as Vestiges of Government Authority Appear to Collapse," Associated Press, April 9, 2003.

[153] Rajiv Chandrasekaran, "U.S. Forces Uncover Iraqi Ex-Leader Near Home Town," *Washington Post*, December 15, 2003, p. A1.

[154] Hans Greimel, "On Both Sides of Conflict, Americans and Iraqis Haul Away Spoils of War," Associated Press, April 8, 2003.

[155] Deborah Orin and Andy Soltis, "Marauding Mobs Play Loot 'N' Shoot," *New York Post*, April 12, 2003, p. 4.

media reports and eyewitness accounts.[156] However, it is impossible to say what percentage of these civilians were killed by U.S. or British forces, as opposed to being victims of Iraqi regular or irregular forces, or to the crime and looting in the aftermath of the government's fall. Another group, Civic, estimated that there were more than 5,000 civilians killed between March 20 and May 1, 2003.[157] The Associated Press' survey of half Baghdad's hospitals found 3,240 civilian deaths between March 20 and April 20.[158] The majority of the civilian deaths appear to have been caused by the ground war. While most of the air war did not seem to harm large numbers of civilians, the "decapitation" strikes aimed at senior Iraqi leaders did appear to result in a disproportionate number of casualties: these fifty or so leadership strikes were often conducted near civilian homes in populated areas and are thought to have caused dozens of casualties in each incident.[159]

During the second phase of operations in Iraq, U.S. and British forces faced Sunni and Shitte insurgents, former Baath party members, and foreign Arab terror groups. These factors often formed various militia groups such as Moqtada al Sadr's Mahdi Army.[160] By late October of 2004, U.S. officials estimated that there were between 8,000 and 12,000 dedicated insurgents in Iraq. Including active sympathizers and accomplices brought this number up to over 20,000.[161] U.S. forces were engaged in a mix of reconstruction and combat activities at once, often engaging in high-intensity urban conflict in areas including Karbala, Najaf, Fallujah, Nasiriya, Basra, Ramadi, Sammara, and Sadr City in Baghdad.[162]

Insurgent attacks on both coalition forces and Iraqi civilians increased in 2004, with bombings and hostage-taking becoming almost daily activities by the latter half of the year.[163] Fallujah was the center of intensified Sunni resistance

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[156] Brad Knickerbocker, "Who Counts the Civilian Casualties?" *Christian Science Monitor*, March 31, 2004.

[157] Jeffrey Gettleman, "For Iraqis in Harm's Way, $5,000 and 'I'm Sorry,'" *New York Times*, March 17, 2004.

[158] "CIA: Iraq Security to get Worse," Cnn.com, November 10, 2003.

[159] Human Rights Watch, pp. 20-3.

[160] Rod Nordland, "Iraq's Repairman," *Newsweek*, July 5, 2004, p. 27.

[161] Eric Scmitt and Thom Shanker, "Estimates by U.S. See More Rebels With More Funds," *New York Times*, October 22, 2004.

[162] Oppenheimer; Terance Nielan, "U.S. Military Pounds Targets in and Around Falluja," *New York Times*, October 15, 2004; Edward Wong, "U.S. Raids in 2 Sunni Towns Anger Clerics and Residents," *New York Times*, October 13, 2004; Steve Fainaru and Khalid Saffar, "Disarmament Process Starts in Sadr City, Albeit Slowly," *Washington Post*, October 12, 2004, p. A1; Steve Fainaru, "Raids Focus on Insurgents South of Baghdad," *Washington Post*, October 6, 2004, p. A18.

[163] Oppenheimer.

during April of 2004. Al Sadr was one of the strongest forces behind Shiite resistance, which manifested itself throughout the year in Karbala, Najaf, Nasiriya, and Sadr City.[164] Despite numerous counter-insurgency operations and negotiated cease-fire agreements with al Sadr's forces, the United States continued to face an ongoing low-level Shiite insurgency for much of 2004. During this period, Iraq also became a magnet for al Qaeda and other terrorist groups. Al Qaeda operative Abu Musad al-Zarqawi's group, Monotheism and Jihad, was thought by U.S. forces to be operating out of Fallujah by the fall of 2004.[165] U.S. forces specifically targeted Zarqawi and his followers during operations in Fallujah in October 2004.[166] During this stage of OIF, insurgents did not appear to actively force civilians to act as involuntary human shields, as the Fedayeen had done during major combat operations. However, insurgents did operate out of heavily populated areas to blend in with the surrounding non-combatants.

Iraq's insurgency continued after democratic elections in January 2005 despite hopes that elections would reduce violence.[167] The year was marked by: an ongoing Sunni resistance, fears of sectarian conflict, violent criminal activity, and additional activity from al Qaeda members in Iraq. Cases of apparent violence between Sunni and Shiite Iraqis became more evident after April 2005, when a Shiite-led government took power as a result of the elections.[168] These included car bombings in Shiite areas of Baghdad; attacks on Shiite pilgrims on their way to Karbala and Najaf; and attacks on Sunni clerics and other prominent individuals.[169] In addition to their usual bombings and kidnappings, in 2005 al Qaeda began targeting diplomats from other Arab countries. In July 2005, the group captured and killed the Egyptian representative to Iraq and kidnapped two Algerian diplomats.[170]

The frequent clashes between U.S. and coalition troops with various insurgents and terrorists in urban areas invariably resulted in civilian casualties

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[164] Oppenheimer.

[165] Fainaru and Saffar, p. A1.

[166] Edmund Sanders and Daryl Strickland, "U.S. Airstrikes Hit Fallouja," *Los Angeles Times*, October 15, 2004.

[167] "Internal Affairs, Iraq," *Jane's Sentinel Security Assessment*, 2005, accessed at Jane's online database on August 5, 2005.

[168] Andy Mosher and Naseer Nouri, "Bombing at Mosque Kills 54 in Iraq," *Washington Post*, July 17, 2005, p. A1.

[169] Mosher and Nouri; and "Worse – and Maybe Better," *Economist*, July 21, 2005, Internet: accessed at www.economist.com on July 28, 2005.

[170] James Glanz, "Terrorist Group Threatens to Kill Abducted Algerian Diplomats," *New York Times*, July 27, 2005.

even after major combat operations were declared over on May 1, 2003. Human Rights Watch reported 20 confirmed and 74 suspected civilians deaths at the hands of U.S. forces in Baghdad between May 1 and September 30, 2003. The organization reported three categories of deaths: those that happened during raids, those who died when military personnel "responded disproportionately and indiscriminately," and those who did not stop at checkpoints.[171] Confusion over instructions, misunderstanding over how to react to U.S. warning shots, nervous sentries, the presence of actual suicide bombers, and the changing location or unexpected presence of checkpoints in Iraq resulted in quite a few civilian casualties. In some of the document cases in Baghdad involving casualties at checkpoints, civilians did not stop because they were unaware of the checkpoint; unaware that they were required to stop at checkpoints; afraid to stop because of hijackers; driving too fast to hear warnings; or driving with music playing too loudly to hear warnings.[172]

Again, many civilians were killed during clashes between U.S. troops and insurgents after major combat operations ended. Many others were killed and injured by insurgent bombs aimed at civilians, or were caught in insurgent attacks directed at U.S. troops, U.S. contractors, and the Iraqi army. During reconstruction, Iraqi civilians also became targets in their own right. Car and suicide bombings became common occurrences in Baghdad and other areas of the country, killing people at mosques, funerals, weddings, checkpoints, employment lines, and other congregation points.[173] (There were 135 car bombings in Iraq in May 2005.[174]) Individual Iraqis perceived to be working with U.S. forces, U.S. contractors, U.S. or international news agencies, or international aid groups were often killed or kidnapped.[175] Members of the Iraqi police and their potential recruits were also frequent targets of bombings and shootings.[176] In addition to deliberately attacking civilians, insurgents also

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171 Karen Matthews, "Human Rights Watch Documents 20 Civilians Deaths in Postwar Baghdad; Dozens More Reported," Associated Press, October 20, 2003.

172 Human Rights Watch, *Hearts and Minds: Post-war Civilian Deaths in Baghdad Caused by U.S. Forces*, October 2003, Vol. 15, No. 9(E) (Washington, DC: Human Rights Watch, 2003), pp. 18-23.

173 Mosher and Nouri; "Worse – and Maybe Better"; "Internal Affairs, Iraq"; Karl Vick and Cameron W. Barr, "Iraqis Begin Voting Amid Violence," *Washington Post*, January 30, 2005, p. A1; and Edmund Sanders, "28 Die in Wave of Insurgent Attacks in Iraq," *Los Angeles Times*, December 29, 2004.

174 Michael E. O'Hanlon and Adriana Lins de Albuquerque, *Iraq Index: Tracking Variables of Reconstruction & Security in Post-Saddam Iraq* (Washington, D.C.: Brookings Institute, 2005), June 30, 2005, p. 9.

175 Onishi; Fred Barbash, "Kidnapped Head of CARE Hassan Pleads for Her Life," *Washington Post*, October 22, 2004; and "8 Iraqis Killed in Attack on Minivan," *Los Angeles Times*, July 19, 2005.

176 Sanders; Michael Georgy, "Newlyweds Shot Day After Their Wedding in Baghdad," Reuters, July 22, 2005; and Mosher and Nouri, p. A1.

used the civilian population as human shields. Although insurgents did not actively force individual civilians between them and U.S. forces, they operated out of civilian areas to blend in with the surrounding population and thus used civilians as involuntary human shields.[177]

Iraqi civilian deaths continued to mount during OIF. Most estimates put total civilian deaths at between 10,000 and 15,000 from the start of OIF in March 2003 through October 2004.[178] In July 2005, the group Iraq Body Count announced that 25,000 Iraqi civilians had died since the beginning of OIF, including Iraqi police, police recruits, and Iraqi army recruits.[179] According to its statement, Baghdad had the highest number of deaths (nearly half) and Fallujah had the second highest. Iraq Body Count noted that civilian deaths had increased over time, with roughly 6,000 deaths the first year after major combat operations ended but about 11,000 deaths the second year.[180] The group also maintained that U.S.-led forces caused 37% of these deaths, criminals 36%, and insurgents 10%.[181] This would suggest that 2,500 Iraqi civilians were killed by insurgents. In contrast, the Iraqi Interior Ministry claimed that 12,000 Iraqis had been killed by insurgents as of June 2005[182] – a figure that would be roughly half of Iraq Body Count's total number of deaths.[183]

Also according to Iraq Body Count, 18% of Iraqi civilians who died within the first two years after the start of OIF were women and children under age 18.[184] The data covered both major combat operations and reconstruction, making it difficult to see how exposure to danger changed for women and children over time. Adult women made up 9% of the dead,[185] consistent with the idea that women restricted their travel during OIF. Fear of sexual assault

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177 Edward Wong, "Provincial Capital Near Falluja is Rapidly Slipping Into Chaos," *New York Times*, October 28, 2004.

178 Norimitsu Onishi, "How Many Iraqis are Dying? By One Count, 208 a Week," *New York Times*, October 18, 2004.

179 This count excluded Iraqi military deaths.

180 "Survey: 25,000 Civilians Killed in Iraq War," Reuters, July 19, 2005; and Alissa J. Rubin, "Report Tallies Almost 25,000 Civilians Slain," *Los Angeles Times*, July 20, 2005.

181 "Survey: 25,000 Civilians Killed in Iraq War," Reuters, July 19, 2005.

182 Sabrina Tavernise, "Data Shows Faster-Rising Death Toll Among Iraqi Civilians," *New York Times*, July 14, 2005.

183 In October 2004, an article in the British medical journal *The Lancet* estimated 100,000 Iraqi civilian deaths during OIF. (See Rob Stein, "100,000 Civilian Deaths Estimated in Iraq," *Washington Post,* October 29, 2004, p. A16.) Other observers have disputed the methodology used by the article authors to arrive at this number.

184 Iraq Body Count, *A Dossier of Civilian Casualties 2003-2005* (Oxford, UK: Oxford Research Group, 2005), p. 2.

185 Iraq Body Count, p. 2.

and abduction in the security vacuum the followed major combat operations lead many families to keep women and girls at home.[186]

There were still instances during major combat operations in OIF when women and children made up a disproportionate number of the casualties. In instances when the violence is brought directly into Iraqi homes, restricting travel does not arguably reduce exposure to danger. In these cases, it is reasonable to expect that women and children among the dead would approach their overall demographic numbers. For example, air strikes aimed at Iraqi leadership targets frequently killed families in their homes. The unsuccessful April 5, 2003 strike against Lieutenant General Ali Hassan al-Majid ("Chemical Ali") in a residential area of Basra killed 17 civilians, including 11 children under age 18 and three adult women.[187] The use of cluster munitions in some areas also increased casualties among children as they had a higher propensity to pick up unexploded submunitions. For example, the use of cluster munitions in the town of al-Hillia on March 31, 2003 left 11 children and four adults dead.[188] Women and children were also a higher proportion of deaths during the ground war in Iraq was the battle for Nasiriyah in March and April 2003. Fighting between Marines and Iraqi forces from March 20 to April 25 resulted in 405 documented civilian deaths directly attributable to the fighting, including 169 children (42% of deaths) and 72 adult women (18% of deaths). The death toll in Nasiriyah during major combat operations was thus 60% women and children.[189]

Overall, Iraqi civilians attitudes towards U.S. troops has been mixed, with some groups hostile, some neutral, and some friendly. This is reflected in the fact that civilians have provided intelligence to both U.S. personnel and to insurgents.[190]

Types of Non-combatant Behaviors

Table 3-1 below summarizes some general case study characteristics. All operations involved high-intensity urban combat but differed in a number of

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186 Human Rights Watch, *Climate of Fear: Sexual Violence and Abduction of Women and Girls in Baghdad*, July 2003, Vol. 15, No. 7(E) (Washington, DC: Human Rights Watch, 2003), pp. 9-10.

187 Human Rights Watch, pp. 28-9.

188 Human Rights Watch, pp. 128-9.

189 Human Rights Watch, p. 132.

190 Thomas E Ricks, "Lessons Learned in Iraq Show Up in Army Classes: Culture Shifts to Counterinsurgency," *Washington Post*, January 21, 2006, pp. A1, A9.

other attributes, such as different operation durations and civilian to U.S. combatant ratios. Reviewing the three case studies shows different civilian characteristics from each operation as well. Civilians in Panama were generally friendly to U.S. forces (with some exceptions) while civilians in Somalia were generally hostile. Iraqi non-combatants were generally neutral during the major combat phase of OIF but more mixed in their responses during the post-conflict period. The case studies also showed the different degrees to which enemy combatants attempted to blend into the civilian population or to otherwise use their presence to their advantage. Panamanian and Iraqi forces both traveled in vehicles that appeared to be civilian. Although Panamanian forces did not appear to do so out of an attempt to disguise themselves among the civilian population, Iraqi combatants during OIF used civilian vehicles precisely for this effect.

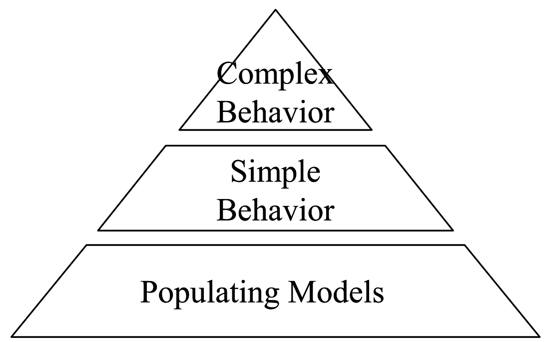
Table 3-1. General Case Study Characteristics

	Panama	**Somalia**	**Iraq Major combat**	**Iraq Post-conflict**
Operation Timeframe	Days	Hours – Days	Weeks	Months
General Civilian Attitude to U.S. Troops	Friendly	Hostile	Neutral - Friendly	Mixed
Combatants Disguised as Civilians	No	Not Deliberate	Yes	Yes
Human Shields	No	Voluntary	Involuntary	Involuntary
Population in Capital During Operation	1.2 million	500,000 to 1 million	5.6 million	5.6 million
U.S. Forces in Country**	22,500	4,500	170,000	110,000 to 150,000
Enemy Combatants	31,900	N/A	N/A	8,000 to 12,000
Citywide Ratio Civilian: U.S. Troops	60:1*	3,000 to 6,000:1	N/A	N/A
Civilian Deaths	202	500+	5,000+	12,000 - 20,000 (July 2005)
U.S. Deaths	26	18	138	1,797 (July 31, 2005)
Approximate Ratio Civilian: U.S. Deaths	8:1	30:1	40:1	7 to 11:1

*Average ratio across Panama City and Colon.
**May be different than forces present in a city.
Source on civilian and U.S. military deaths: Glenn, et. al. for Panama; Allard and Glenn, et. al and Somalia; Civic, Onishi, Tavernise, O'Hanlon and de Albuquerque, and GlobalSecurity.org for Iraq.

This dissertation proposes a layered approach to introducing civilian behavior in models, simulations, and other types of analysis.

Figure 3-2. Modeling Non-combatant Behavior



It is best to begin with general civilian population demographics when thinking about non-combatants in urban operations. Often, a first approach to thinking about non-combatant behavior in models and simulations is to begin with the advanced, complex behaviors that require specific goals and interaction between non-combatants and combatants. However, general population characteristics provide the context for non-combatant behavior and may be thought of as the base layer in a framework for incorporating non-combatants into military models and simulations. The next layer is simple behavior that civilians most commonly exhibit in urban settings, such as daily travel, and reflexive reactions to combat. Many of the simpler behaviors may be more universal than complex behaviors and are important in their own right for understanding civilian casualties and the operational challenges that U.S. forces face in densely populated areas. The final layer is complex behavior that requires purposeful action on the part of civilians and a more sophisticated level of interaction with enemy and U.S. combatants. The layers build on one another with the lower ones, providing context and support for the upper ones.

The simple and complex behaviors identified in this dissertation were the ones that stood out in the case studies as having the greatest impact on U.S. military operations and on civilian casualties. Simple behaviors provide the backdrop and context for more complex ones. They also appear more frequently than complex behaviors. Simple physical movement includes background activity, such as commuting, travel, and congregation:

Table 3-2. Travel and Congregation During Operations

	Panama	Somalia	Iraq Major combat	Iraq Post-conflict
Commuting/Travel	Yes	Yes	Yes	Yes
Congregation	Limited	Yes	Yes	Yes

Travel, commuting, and congregation were universal behaviors across all three cases studies. Although the extent to which civilians showed these behaviors varied, they appeared in all three case study countries even during very different types of urban operations. A look at non-combatants in the case studies showed that background behavior was fairly universal. Simple behaviors also include simple reactions to combat: running from fighting, taking shelter, ignoring combat, and running towards fighting.[191]

Table 3-3. Simple Civilian Reactions to Combat

	Panama	Somalia	Iraq Major combat	Iraq Post-conflict
Run Away	Yes	Yes	Yes	Yes
Take Shelter	Yes	Yes	Yes	Yes
Ignore Combat	Vehicles	Uncertain	Vehicles, Some pedestrians	Vehicles
Run Towards	No	Yes	No	No

Most of the simple reactions to combat (running away, taking shelter, ignoring the fighting, and running towards it) also appeared to be near-universal responses. Non-combatants in the case studies exhibited the first three behaviors to varying degrees. Running away from combat and taking shelter were evident among civilians in all case studies. For example in Panama, civilians ran from firefights, often using lulls in the fighting to run away from the proximity of combatants. The fires in Colon also caused people to flee certain areas. Many Somali civilians also ran away from the fighting and sought shelter, even as others were running towards combat at the same time. Iraqi civilians also frequently showed these two behaviors. Seemingly ignoring combat was also a trait found among civilians in both Panama and Iraq, particularly those in

[191] Civilians may have various motives when they display these behaviors. For instance, civilians that appear to be ignoring combat may be unaware of their situation, or may underestimate the danger they face.

vehicles. On the other hand, only Somali civilians ran towards the sound of fighting and congregated at the scene.[192]

Civilians in the case studies also displayed behavior that could be considered complex. The following table is not meant to be an exhaustive list of all the complex behavior that non-combatants in these three cases exhibited. Instead, it identifies some of the more notable complex behaviors found during these operations. The ones examined in this dissertation are looting, acting as human shields, attacking U.S. forces, and swarming. Although the simple behaviors discussed above had interaction between civilians and combatants, this interaction is best characterized as unplanned or reflexive. On the other hand, these complex behaviors begin to incorporate purposeful and directed interactions between civilians and enemy combatants or U.S. forces. With some of the behaviors, non-combatants begin to cross the line into becoming combatants themselves.

Table 3-4. Complex Civilian Reactions to Combat

	Panama	Somalia	Iraq Major combat	Iraq Post-conflict
Looting	Yes	No	Yes	No
Involuntary Human Shields	No	No	Yes	Yes
Voluntary Human Shields	No	Yes	No	No
Attacking U.S. Forces	Yes (Rare)	Yes (Common)	Yes (Rare)	N/A
Swarming	No	Yes	No	No

Compared with the simple behaviors listed in Tables 3-2 and 3-3, the complex behaviors above are much more likely to be situation-specific. In other words, all non-combatants in each of the case studies displayed some of the simple background behaviors such as traveling and running from combat; but whether or not they looted or attacked U.S. forces varied on a case-by-case basis. Identifying which of the listed complex behaviors appeared in each case study gives a feel for the civilian environment that U.S. troops encountered in each operation. For instance, civilian attacks on U.S. forces in Panama and Iraq during major combat operations were generally isolated cases. In contrast, in

192 There appear to be very few instances of this behavior anywhere outside the Somalia case. From a modeling prospective it is still a simple reaction to combat and will be discussed in the chapter on simple non-combatant behavior.

Somalia, it was common for civilians to attack U.S. troops, to act as voluntary human shields, and even to swarm – a complex behavior on the battlefield generally associated only with combatants.

Following the layered approach suggested above, the following chapters begin with the simplest facts about non-combatants and build up from that point. Thus, Chapter 4 discusses populating military models and simulations with non-combatant actors. Chapter 5 discusses simple behaviors such as background activity and simple reactions to combat. Chapter 6 continues on to complex behaviors. Each layer of non-combatant attributes or behaviors builds on the next, with simple and widely applicable attributes at the bottom of the pyramid and complex and situation-specific ones at the top. The remainder of Chapter 3 presents a brief summary of the non-combatant behaviors that will be discussed.

4. Populating Models with Non-combatants

How should the United States think about conducting operations in highly populated areas? Chapter Four discusses beginning with the simple step of populating models with non-combatants. Analytically, this is the first building block in modeling civilians. Introducing the proper non-combatant population density and ratio to combatants is a starting point for understanding the scope of how non-combatants may impact events. There are insights to be gained from merely populating models with non-combatants in numbers that reflect real-life cities. Even before discussing non-combatant behaviors, doing so allows for consideration of civilian casualties, operational challenges, and force structure requirements. It is also a good beginning for modeling something as complex as non-combatant behavior in urban operations. This is because starting with a stationary population of non-combatant agents is analogous to creating a model with simple assumptions and exploring the implications before going on to more sophisticated inputs and functions. Rather than starting with a few highly complex non-combatant actors in a model, it is simpler and more analytically robust to begin with simple questions about the scale of a non-combatant population in a model. Starting with the numbers of non-combatants in a given urban area is to begin with the most general characteristic of a non-combatant population, rather than to begin with highly specialized and situation-specific non-combatant agents.

This philosophy of beginning with the simplest assumptions and building up to more complex ones is reflected even within this chapter. The first section elaborates on the importance of incorporating the correct scale of non-combatants in a model. The section that follows on population density introduces the simple assumption of a civilian population that is stationary, homogeneous, and uniformly distributed. The next section discusses expanding on this assumption by adding heterogeneity in a population – heterogeneity in density, demographic characteristics, casualties, and other attributes. The following section deals with changes in density and heterogeneity over time. The final section of Chapter 4 provides an example of how using population density can result in relevant analysis on a policy problem.

Importance of Scale

As previously argued, many current military models and simulations do not include non-combatants. Where they do, combatants usually vastly outnumber non-combatants. Although this is the current norm in the military simulations, it would be useful to populate models with non-combatant population densities that better reflect real-world levels. There are several reasons why military models would be enhanced by the addition of non-combatant actors on the correct scale.

First, it begins to give a picture of the correct magnitude of civilian casualties one could expect from an operation. Second, it gives a more realistic picture of the operational challenges that U.S. forces may face even among a large number of neutral civilians. Even when civilians are relatively passive or seeking to stay out of the way of the fighting, their mere presence may complicate matters. Analysis that explicitly deals with population numbers can highlight implications for planning and other issues. Scale begins to matter particularly as some effects are exponential rather than linear. Third, scale affects force structure requirements. Introducing the correct order of magnitude of an urban population allows for basic force structure modeling and understanding of force requirements. Fourth, combatant and non-combatant interactions in real life can have dramatic effects on casualties and mission objectives. Having non-combatants in a model at the correct scale is arguably a necessary precondition to fully see these effects in the analytic tools that the defense community uses to make policy decisions.

To expand on the first point, civilian casualties are a major concern when using military force in urban areas. By definition, these areas have large numbers of non-combatants who can be harmed or killed by U.S. operations. In addition to basic concern for human life, non-combatant deaths can also lead to political backlash and to operational constraints. Instantaneous media coverage of conflicts, the advent of precision weaponry, and increased sensitivity over civilian deaths since World War II have changed the norms about what level of civilian casualties are acceptable. During World War II, the tens and even hundreds of thousands of civilians killed by the U.S. firebombing of German and Japanese cities did not result in pressure to scale back these attacks. In contrast, the United States significantly decreased bombing operations in Baghdad after planners unwittingly killed hundreds of Iraqi civilians in a shelter at the Al

Firdos command, control, and communications facility during the 1991 Gulf War.[193]

Adding more realistic non-combatant population densities to models would begin to allow decision makers to see the type of casualties that they may expect in real cities. At these higher levels of simulated casualties, slight shifts in weapons parameters or tactics may produce noticeable changes in casualties that may not have been statistically significant in a simulated environment that consisted of relatively few civilians. Another aspect of population demographics not yet incorporated into existing models is differentiation by age and gender. There is greater sensitivity to deaths among women and children during actual operations, yet non-combatants in most models are homogeneous. The United States is also more likely to conduct operations in developing countries where there are a high percentage of young children. Models with greater population densities will naturally show larger numbers of such sensitive casualties.

On the second point, increased civilian population densities in models should also better highlight some of the operational difficulties that U.S. troops on the ground face in urban areas. However, the potential extent of such difficulties is not visible in models that are sparsely populated with non-combatants. For example, the problem of clutter, situational awareness, and successfully enemy identification in a densely populated city may not seem to be a major issue in a simulation or real-life exercise where combatants significantly outnumber non-combatants. However, this problem could easily start to look overwhelming when non-combatants outnumber combatants by a thousand or more to one. This would be especially true if there are disadvantageous nonlinear or threshold effects for sensors, communications networks, and other attributes that would otherwise enable better situational awareness. This magnitude of sensory clutter would also become an important consideration when simulating the value or the effect of information in urban terrain.

Clutter from high concentrations of non-combatants is especially important when simulating the performance of innovative programs such as Future Combat Systems (FCS), which rely heavily on superior situational awareness for survival. In the wake of OIF, some have raised doubts about the potential survivability of FCS in an urban setting. FCS depends heavily on information superiority for survival, but critics have noted that such superiority is far easier against conventional armored vehicles in a conventional war than

193 Eric Schmitt, "A Nation at War: Civilians; Rumsfeld Says Dozens of Important Targets Have Been Avoided," *New York Times*, March 24, 2003, p. B12; and William M. Arkin, " Baghdad: the Urban Sanctuary in Desert Storm?" *Airpower Journal*, Vol. 11 (Spring 1997), pp. 13-4.

during stability and peace operations in an urban environment where combatants blend in with non-combatants.[194] Given the requirement that the FCS be able to operate across the spectrum of conflict, it would be important to understand its potential in urban settings. Dramatically increasing the number of non-combatant actors in simulations of FCS deployment is a simple way to begin exploring this question.

On the third point, the scale of a civilian population will have force structure and force sizing implications in urban operations. Dramatically increasing population densities even in very low-resolution analytic models begins to yield insights about force structure and manpower requirements that would not have been obvious with the way models are currently populated. As has been frequently discussed in the urban operations literature, cities in most areas of the world are becoming more and more populated. For example, urban combat in modern day metropolitan Seoul would be vastly different from what it was over fifty years ago during the Korean War when the city was unindustrialized and far smaller. The dramatic increase in population and urban structures in that city since the 1950s would increase both the intensity of urban warfare and the size of a force required to secure and hold the city.[195] The manpower requirement for some types of peacekeeping and stability operations is also proportional to the size of the surrounding civilian population. Larger civilian populations require greater numbers of military police to provide security, civil affairs personnel for manage relations, and engineers to run or repair urban infrastructure. (One criticism of OIF is that the U.S. failed to have enough troops on the ground in Baghdad to manage the security situation in the city immediately after the fall of Saddam Hussein's government.[196])

Lastly, on the fourth point, few models currently employ the kinds of civilian-combatant interactions that often mark actual urban operations. The presence and behavior of non-combatants is background to the drama between red and blue in most current models. Non-combatant behavior and casualties are often side outcomes in a model run and do not in and of themselves affect the primary results: red casualties, blue casualties, and other measures of effectiveness for the simulated mission. A few models that concentrate on stability and support operations (SOSO), such as DIAMOND, do incorporate non-combatant behavior into the outputs and measures of effectiveness used to

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194 Joshua Kucera, "Iraq Conflict Raises Doubts on FCS Survivability," *Jane's Defence Weekly*, May19, 2004.

195 Glenn, Steeb, Matsumura, p. 3.

196 Robin Wright and Thomas E. Ricks, "Bremer Criticizes Troops Levels," *Washington Post*, October 5, 2004, p A1.

evaluate model results. However, it is usually the case that non-combatants are afterthoughts who have little impact on combatant activities in a simulated battle. Again, this is in contrast to the reality of urban operations, where non-combatants often effect or even direct events. Increasing the number of interactive non-combatants by a few orders of magnitude in a simulation should better allow for the recreation of a challenging urban environment and would set the groundwork for analyzing the effects of more complex civilian actions. Further developing these analytic tools should help policy makers in urban operations decisions ranging from equipping platforms to providing guidance to troops on how to interact with non-combatants.

Non-combatants can have a substantial impact on the course of events in an urban operation. This not to say that they always do: they did not appear to hinder U.S. forces in Colon (Panama) in 1989 or the initial armored force in Baghdad in 2003 from achieving their combat objectives. Instead, the point is that they may and that populating models correctly is the start of taking this into consideration. There were isolated incidents in all three case studies where civilians attacked U.S. troops. However, it was only in the case of Somalia that civilians drastically hindered U.S. operations because the high prevalence of this behavior plus an urban population density produced a situation that overwhelmed U.S. personnel. In any mental or computer model of U.S. forces confronting hostile civilians, the possibilities for what can happen expand as the number of hostile civilians for each U.S. serviceman present also expand. Non-combatant behavior will be elaborated upon in Chapters 5 and 6, but it is argued here that many non-combatant behaviors need to be taken in the context of the sheer number of individuals who may be engaged in that behavior to fully appreciate its effects on non-combatant casualties and U.S. military operations. In some types of missions, such as stability operations, non-combatant considerations are not only important but also paramount to success.

Population and Population Density

This section explores the implications of population size and uniform population density. Merely using citywide data on population, population density, and combatant to non-combatant ratios may be sufficient to answer some simple questions about civilian casualties, force structure requirements, system performance, situational awareness, or planning. This is before taking into account *any* other information discussed in the rest of the chapter, such as heterogeneity, or any of the non-combatant behaviors dealt with in later chapters.

As noted in the previous section, fairly basic information on population size and combatant to non-combatant ratios is enough to conduct basic analysis on force sizing. Peacekeeping, counterinsurgency, and stability operations are all tasks where manpower requirements are primarily a function of the civilian population.[197] Different force-to-civilian ratios are needed for scenarios and different levels of security requirements. Estimates based on past operations show that a troop level of 1 to 4 per thousand of the population is in the range sufficient for daily policing activities in a peaceful population. Troop levels of 4 to 10 per thousand are more appropriate for some stability and counter-insurgency operations. In more demanding stability and counter-insurgency situations, troop levels of greater than 10 per thousand are appropriate.[198] Force sizing does depend on the degree of resistance or conflict that U.S. forces may expect to face, but population size is a key driver for manpower requirements. Parametrically estimating force structure requirements using ratios (1 to 4 per 1,000; 4 to 10 per 1,000, etc.) also explicitly spells out what assumptions are being made about a city's security environment. Using the populations in some of the case study cities during U.S. military operations, the following table provides estimates on the level of forces that might have been called for:

Table 4-1. Potential Troop Requirements for Peacekeeping and Stability Operations

	Panama City (1989)	**Mogadishu (1993)**	**Baghdad (2003)**
Population	1.2 million	500,000 to 1 million	5.6 million
Troops for daily policing of peaceful population	1,200 to 4,800	500 to 4,000	5,600 to 22,400
Troops for some stability and counterinsurgency operations	4,800 to 12,000	2,000 to 10,000	22,400 to 56,000
Troops for demanding stability and counterinsurgency ops	12,000+	5,000 to 10,000+	56,000+
Actual ground forces	22,500 in Panama City and Colon area	About 160 in Task Force Ranger	N/A* (140,000 in Iraq)

*Number of U.S. troops in Baghdad during various phases of OIF is generally not available.

197 James Quinlivan, "Force Requirements in Stability Operations," *Parameters*, Vol. 25, Winter 1995, pp. 59-69. Note the argument that the level of counterinsurgency forces required depend on the size of the civilian population and *not* the size of the counterinsurgency force.

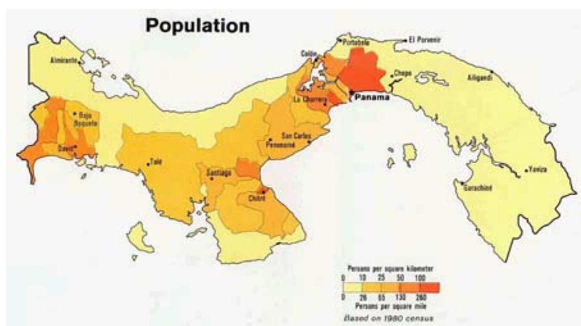
198 Quinlivan, pp. 59-69.

According to these estimates, with over 22,000 troops, the United States should have been enough forces in Panama to deal with the fairly friendly population after the fall of the Noriega government. Somalia was a more challenging environment with a much lower number of directly involved U.S. personnel per population. The 1993 raid in Somalia was not technically policing, stability, or counterinsurgency. However, these estimates do show that a force substantially larger than Task Force Ranger would have been needed for population control, should that have been the requirement. For Iraq, it is difficult to estimate how many of the 140,000 U.S. and coalition personnel present during post-conflict operations were assigned to Baghdad at any given point in time. With a total population of about 25 million in Iraq, these ratios would suggest 25,000 troops in the entire country to police a peaceful population and 250,000 or more to deal with active counterinsurgency and difficult stability operations throughout all of Iraq.

The next concept to explore after population is population density – the size of a population per square area. At its most basic level, urban operations are combatants and non-combatants operating within a geographical space. The simplest approach to modeling urban operations would use population densities to describe the distribution of non-combatants. Even information on the average population density of an area, without knowing further detail about the actual distribution, is data that can be useful in different types of analyses. Average population density will reflect a lower bound for the actual concentration of people in a given physical space. This is because people do not uniformly spread out over an area but cluster. However, it may be that even the average population density of an urban area poses sufficient operational challenges to strongly suggest that the real-life scenario would be even worse. For example, weapons systems in development are often tested through high-resolution modeling and simulations. Using average density and not even taking crowds or other high concentrations of non-combatants into account, how does a system fare in an urban environment? Is a system able to retain situational awareness despite a certain density of civilians surrounding it? Does the amount of clutter sharply reduce a hypothetical system's information superiority? Does it need to dramatically increase the number of rounds the system fires before a certain number of the enemy has been engaged? Does this cause more civilian casualties?

Another use for basic population density information is to establish a baseline for non-combatant casualties. One may begin with a proposed uniform population density for a city and add assumptions about munitions effects and shielding from structures. It would then be possible to approximate a baseline number of civilians killed and injured from air strikes, land-based indirect fire, direct fire, and other sources of death and injury from combatants on the battlefield with such a distribution. (For low-resolution models that incorporate only about this level of fidelity, this may be the only model output that deals with non-combatants.) It is then possible to ask questions using this baseline. For example, what happens as the distribution of non-combatants is no longer uniform but more concentrated in some areas? Is there additional value to information about the way a population is distributed throughout a city? How do different tactics and munitions affect non-combatant casualties as one operates in cities that are more highly developed or geographically more differentiated?

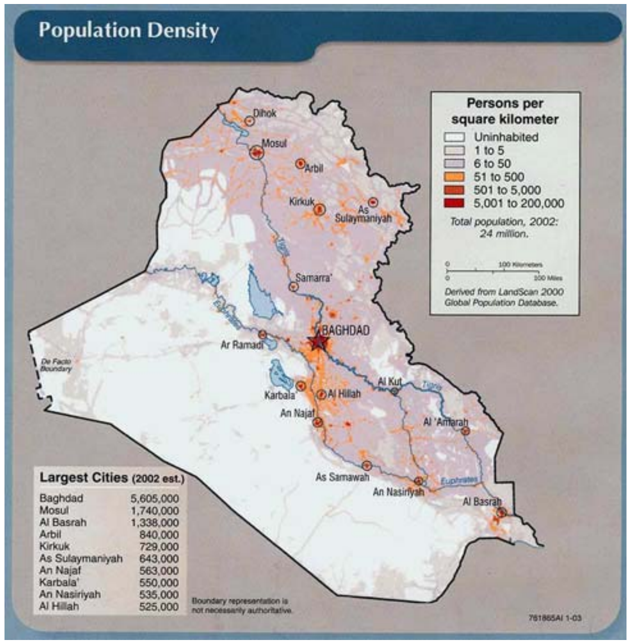
Figure 4-1. Population Density of Panama, 1980



Source: CIA.

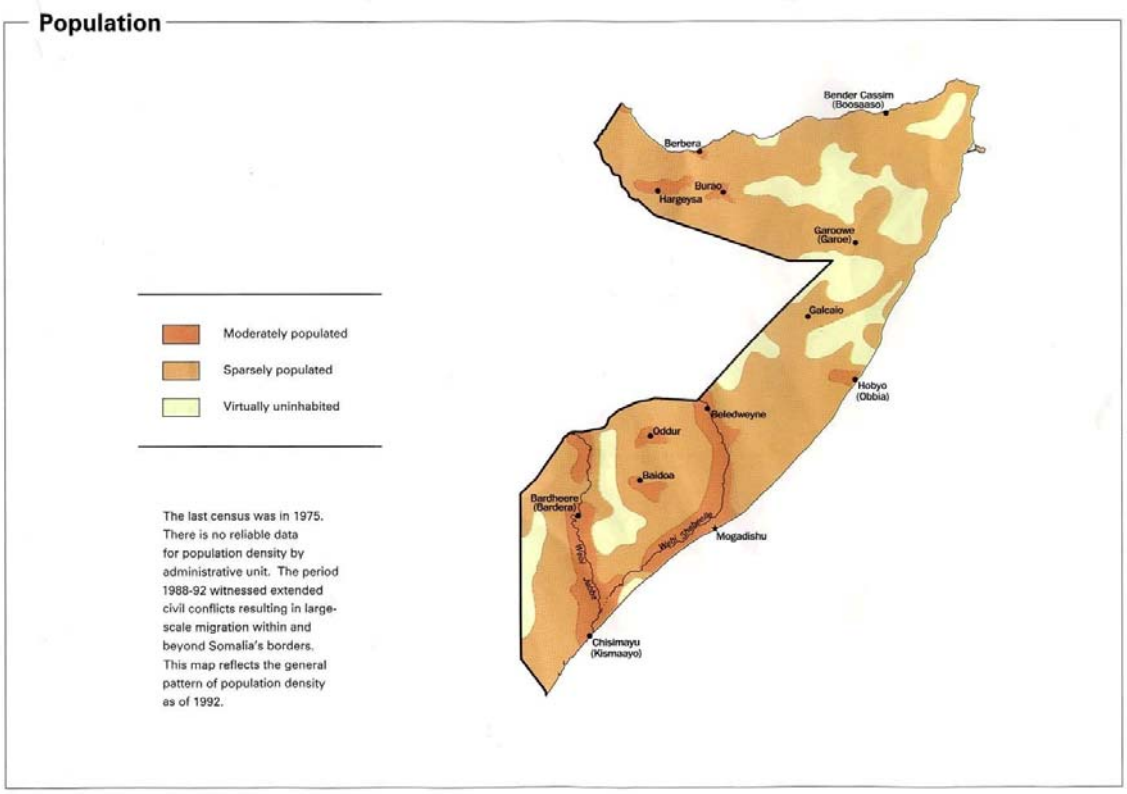
Figures 4-1 and 4-2 show the approximate population densities of Panama City, Colon, and Baghdad from 1980 Panamanian census data and 2000 Iraqi population estimates. Figure 4-3 gives a rough outline of Somalia's population distribution in 1992:

Figure 4-2. Population Density of Iraq, 2000



Source: CIA.

Figure 4-3. Estimated Population Distribution of Somalia, 1992.



Source: CIA.

As may be seen, the highest population densities tended to be in and around capital cities. Using approximate square areas for these cities, it is possible to estimate the average population density that U.S. troops encountered in during various operations. Figure 4-4 below gives provides a close-up look at Baghdad at the beginning of Operation Iraqi Freedom. Using Figure 4-4, it is possible to calculate a rough estimate of Baghdad's average population density in 2003. Drawing a circle with a diameter of 15 miles around the center of the city gives an area estimate of approximately 177 square miles. With a population of 5.6 million, this would give Baghdad an average population density of roughly 31,600 people per square mile.

Figure 4-3. Map of Baghdad, 2003

Source: National Imagery and Mapping Agency.

Figure 4-5 is a map of Mogadishu. The area inside the yellow rectangle and triangle is approximately 16 square miles. With an estimated population of 500,000 to 1 million in 1993, Mogadishu had roughly 31,000 to 62,000 people per square mile:

Figure 4-4. Map of Mogadishu

Source: GlobalSecurity.org.

These two estimates imply that the average population density in Mogadishu in 1993 may have been higher – even double – than the average density in Baghdad in 2003. For comparison, the following table shows population densities of several other large cities around the world. Many of these cities have population densities on the same order of magnitude as the estimates for Mogadishu and Baghdad:

Table 4-2. Population and Average Population Density for Select Cities

Urban Area	Country	Year	Population (Millions)	Area (Sq Miles)	People per Sq Mile
Los Angeles	USA	2000	3.69	238.7	7,878
Mexico City	Mexico	2000	8.59	579.0	14,838
San Paulo	Brazil	2000	9.84	576.0	17,082
New York City	USA	2000	8.01	309.0	25,917
Tokyo	Japan	1995	7.97	238.7	33,379
Buenos Aires	Argentina	1990	2.96	77.0	38,455
Seoul	South Korea	1990	10.73	237.0	45,257
Manila, City of	Philippines	1990	1.63	14.7	110,917
Calcutta	India	2001	4.58	40.7	112,569
Hong Kong	China	2001	3.44	26.8	128,432
Lagos	Nigeria	2001	7.72	56.0	137,857

Source: U.S. Census Bureau for U.S. data, Demographia for international data.

Although the discussion has been focused on large cities so far, smaller cities and towns with lower population densities still matter. For one, civilian casualties in more sparsely populated cities may still be a galvanizing event. In February 1994, Serb forces shelled Markale marketplace in Sarajevo, killing 68 civilians and wounding 200 more.[199] The event focused international attention on the conflict in the Balkans and prompted NATO to threaten airstrikes against Serb guns outside the city.[200] Additionally, looking forward, U.S. forces can expect to fight in smaller cities as well as in larger and more heavily populated ones. In Panama, U.S. forces fought in Colon, a relatively small city of 60,000, as well as in the capital of Panama City. Soldiers and Marines in Iraq often encountered Fedayeen and other fighters in the smaller cities and villages on their way to Baghdad. In anticipating a potential war in a capital city such as Seoul, it may be best to also consider the fighting that is likely to happen in the city's suburbs and smaller neighboring cities.

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[199] Roger Cohen, "Shelling Kills Dozens in Sarajevo," *New York Times*, August 29, 1995, p. A1.

[200] Cohen, p. A1.

Another form of non-combatant density is civilian vehicle density in an urban area. Vehicles also add to the clutter and confusion that U.S. troops must deal with in an urban environment. In Panama and Iraq, non-combatants frequently died in vehicles that were caught in crossfire or that were mistaken for enemy combatants. In Iraq during major combat operations, Fedayeen blended in with civilian vehicles while attempting to attack U.S. ground forces or to use civilians as involuntary human shields. The U.S. had difficulty dealing with civilian vehicles even during post-conflict operations in both Panama and Iraq, when they needed to sort out harmless but erratically behaving vehicles from genuine threats at checkpoints and roadblocks. Old and abandoned vehicles can create another set of problems. These add to clutter, especially in wooded areas, when U.S. forces attempt to scan for targets using foliage-penetrating radar and other imagery technology.

Table 4-3 below gives vehicles per 1,000 people and average vehicles per square kilometer for select countries. Locally, vehicle density will depend on factors such as population, road networks, driving conditions, and even the time of day, week, or year. Overall, Table 4-3 should give some idea of the number of vehicles expected on the road for a given level of industrialization. If U.S. forces are more likely to enter conflicts in developing countries in the future, it follows that the vehicle density they encounter will actually be at the lower end of the spectrum. However, this is not to say that the gross numbers are inconsequential. A moderately advancing country may still have enough vehicles in a large city to pose operational problems for U.S. forces. The one notable exception to the idea that U.S. forces are more likely to conduct urban operations in developing world cities in the future is the potential confrontation with North Korea in Seoul. As a rapidly advancing country and an exporter of motor vehicles, South Korea has a high number of cars per capita. There is a joke in Seoul that if North Korean tanks ever invaded the city, they would get stuck in rush hour traffic. With one million registered vehicles and traffic jams that sometimes persist beyond midnight, vehicle traffic in Seoul could pose enormous headaches for a conventional armored force seeking to operate in the city.[201]

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[201] SeoulSearching.com; Internet: accessed at www.seoulsearching.com on August 31, 2004. Related to growing urban populations is the constant construction of new urban and suburban structures on land that was previously unused or used or agricultural purposes. Multi-story construction, the presence of basements, and other factors all lead to the creation of more and more urban and built-up terrain.

Table 4-3. Vehicle Densities For Select Countries

Country	Motor Vehicles per 1,000 Persons	Year	Vehicles per Sq. Km (1996-99)	Est. Vehicles per Km Road
United States	765	1996	46.56	
Italy	566	1994	115.31	
United Kingdom	426	1995	101.40	
Saudi Arabia	336	N/A	3.68	
Argentina	170	1995	4.67	
Mexico	138	1997	10.91	
Russia	124	1996	5.66	
Panama	97	1997	5.59	
Iraq	50	1995	2.54	
Iran	23	N/A	1.66	
China	10	1997	1.77	
Pakistan	8	1997	1.58	
Angola	4	1995	0.45	
Somalia	3	N/A	0.01	
Chad	3	N/A	0.08	
Bangladesh	2	1996	0.97	
Afghanistan	0.0	1995	N/A	

Source: United Nations Statistical Yearbook 2003 and World Statistics Pocketbook 2003; World Bank Development Indicators 2001; CIA World Factbook 2003

Table 4-3 shows notable differences in the number of motor vehicles per 1,000 of a country's population. The most advanced industrialized country in the world, the United States, had 3/4th of a vehicle for every person eight years ago. The ratio for poorer and less industrialized countries drops off steeply. Afghanistan, for example, had less than one tenth of a vehicle for every 1,000 of its citizens in 1995. Table 4-3 also gives the average number of vehicles per square kilometer over a country's total area. However, citywide vehicle densities would be more useful, just as average citywide population density gives greater information for operational questions than average national population density. Alternatively, the number of vehicles per kilometer of road would be a more useful metric. This is because motorized vehicles are generally confined to roads and are not at liberty to roam the entire area of a country or city.

Table 4-4 below gives approximations for the number of motorized vehicles in the case study cities by combining a city's population data with the per capital vehicle counts from Table 4-3. The reader should be aware that population estimates and per capital vehicle data are from different years and that the estimated number of vehicles is a rough approximation only. There are also likely to be different rates of vehicle ownership in a country between highly populated urban areas and other portions of the country. This leads to rough citywide vehicle estimates that might be the correct order of magnitude, but may still differ substantially from actual counts. For example, for the number of vehicles in Baghdad during OIF, one might estimate (at 50 cars per 1,000 people in 1995) at least 280,000 vehicles in the city. In reality, there were 500,000 private vehicles in Baghdad in April 2003 and over 1 million private vehicles in Baghdad by January 2004.[202] Using an estimate of 177 square miles for Baghdad, this would mean a vehicle density of 2,800 per square mile at the start of OIF and a density of 5,600 vehicles per square mile less than a year later. In contrast, Mogadishu may have had 190 to 380 vehicles per square mile in 1993.

Table 4-4. Estimated Number of Vehicles for Case Study Cities

City	Population	National Vehicles per 1,000	Estimated Vehicles
Panama City	1.2 million (1990)	97 (1997)	116,400+
Colon	60,000 (1990)	97 (1997)	5,820+
Mogadishu	500,000 to 1 million (1995)	3	3,000-6,000+
Baghdad	5.6 million (2002)	50 (1995)	280,000+ (Actual: 500,000)
Basra	1.3 million (2002)	50 (1995)	65,000+

Source: Data from Tables 4-1 and 4-3.

Table 4-4 shows that even though vehicle density would be relatively low for the case study cities compared with advanced industrialized cities, the gross numbers of vehicles involved are still substantial.[203] Finding hundreds of Fedayeen vehicles or screening for individual suicide bombers among 500,000 vehicles in Baghdad is not an easy task. Even screening the few thousand vehicles that might be present in a less advanced city such as Mogadishu could pose problems, particularly for a small U.S. force. The U.S. experience in Haiti during the 1990s illustrates how civilian vehicles can affect operations even when a country is not heavily industrialized. At the beginning of U.S. operations in that country, there was little civilian road traffic due to an oil embargo that had been placed against the country. As a result, U.S. military vehicles were able to travel freely. However, after the end of the embargo, civilian traffic increased

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[202] Brig. Gen. David N. Blackledge, "Coalition Provisional Authority Briefing, Commander's Emergency Response Program." U.S. Department of Defense briefing, January 14, 2004. Internet: accessed at http://www.defenselink.mil/transcripts/2004/tr20040114-1144.html on October 29, 2004.

[203] It would also seem reasonable to assume different distributions in rural versus urban areas. Urban areas may have a higher number of vehicles per population, given higher incomes to support private vehicles, higher numbers of people to support buses and taxies, and higher economic activity to support commercial vehicles.

considerably and often forced U.S. personnel to travel by helicopter.[204] Although civilian traffic may appear to be a mundane topic at first glance, it can cause genuine operational issues.

Introducing Heterogeneity

So far the discussion has been on a homogeneous, uniformly distributed non-combatant population. In real life, non-combatants are heterogeneous is almost unlimited ways. This section discusses heterogeneity in demographic characteristics, population density, casualties, structural shielding, propensity to be friendly to U.S. forces, and ratio to combatants. It discusses how population heterogeneity affects military operations and discusses how these lessons may be applied to modeling non-combatants. This section is meant to complicate the assumption from the previous section of a uniform civilian population and to explore how assumptions about heterogeneity can be used in models and simulations.

First and foremost, as mentioned earlier, an urban population is heterogeneous with regard to age and gender. There is nothing in current military models that differentiate non-combatants along these lines, even as sensitivity for these types of casualties have consequences for the U.S. military.[205] At the same time, it is very easy to add heterogeneity by gender and age. This is especially true for agent-based models and this is one of the notable strengths of this technique. Most populations are roughly half male and half female. In developing countries such as Panama, Somalia, and Iraq, the population pyramid also shows a high number of children. This tends to be a result of higher birth rates and shorter life expectancies for older members of the population. Table 4-5 below shows the age distribution for countries in the three case studies, plus the distribution for the United States and Japan for comparison:[206]

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[204] Russell W. Glenn, Steven L. Hartman, and Scott Gerwehr, *U.S. Combat Service Support Operations: the Shoulders of Atlas* (Santa Monica, CA: RAND Corporation, 2003) p. 51.

[205] One or two of the crowd dynamics models discuss heterogeneity in physical characteristics, noting that members of different genders and ethnicities should be represented by smaller agents. See work by Keith Still for an example.

[206] Although the United States is an advanced industrialized country, its population growth rate is higher than for most other industrialized countries because of immigration and the higher birth rates of some recent immigrants. In contrast, Japan is a country with much less immigration and a negative population growth rate due to falling birth rates. Several other industrialized countries are known to have declining growth rates and aging populations.

Table 4-5. Age Distribution for Case Study Countries

Country	Total Population	Age 0-14	Age 15-65	Age 65+
Panama (1990)	3,538,976	57.3%	39.3%	3.5%
Somalia (1975)	4,089,203	46.6%	50.3%	3.1%
Somalia (2003)	8,025,190	44.8%	52.5%	2.7%
Iraq (2003)	24,683,313	40.7%	56.3%	3.0%
United States (2004)	293,027,571	20.8%	66.9%	12.4%
Japan (2004)	127,333,002	14.83	66.7%	19.0%

Source: U.S. Bureau of the Census International Database. CIA *World Factbook 2004* for 2003 Somalia and Iraq statistics.

A fairly large percentage of the population for the case study countries was under age 15 during the years that U.S. military operations took place. In Panama in 1990, it was well over half of all Panamanians; in Iraq during OIF, children under 15 still made up slightly over 40% of the population. There were no data on the percentage of Somalis who were under age 15 during the mid-1990s, but the nation's population survey in 1975 and a population estimate in 2003 put both put the percentage of children in that age range in the mid-40s.[207] Since the end of the Cold War, the United States has conducted military operations primarily in developing countries where this type of population pyramid is common. In contrast, children tend to make up a smaller percentage of the population in advanced industrial countries such as the United States and Japan. One should note that these are age pyramids for these countries as a whole. The percentage of young children should be a lower for an urban population, although the gross number will still be quite large. This is because urban areas, even in developing countries, tend to have better nutrition, medical services, and higher levels of education for women. This tends to lead to lower birth rates, more children surviving into adulthood, and longer life expectancies.

Even though children may make up a sizeable portion of a city's population, it does not necessarily hold that they will automatically constitute the same percentage of those killed or injured. This is because women and children may be in different places than men or have different exposures to combat. It may also be because combatants are more likely to consider civilian men as threats or potential enemy combatants, whereas women and children are usually seen as non-combatants. On the other hand, where there is much more difficulty in distinguishing between combatants and non-combatants, women

[207] However, U.S. intervention in Somalia in 1993 was triggered by famine conditions in that country. During famine, one would expect small children, those under age five, to be most likely to die from the effects of malnutrition and disease. The actual percentage of children under age 15 may thus have actually been lower during this time.

and children deaths will be closer to their overall demographic numbers. Although statistics on the breakdown of civilian casualties are not always complete, women and children appeared to make up different proportions of the dead and injured in the case studies.

The discussion of Operation Just Cause in Chapter Three included the estimate that 13% of Panamanian civilian deaths were women and children. This is compared to the fact that 79% of the Panamanian people as a whole were children under 15 (58%) or women age 15 and over (21%). It is impossible to pinpoint exactly what factors led to this. However, there are a number of plausible influences. It would seem that U.S. forces had some success in distinguishing likely targets from the general population. Civilians also did not interfere in the fighting, U.S. troops maintained a good degree of control during the operation, combatants did not use women and children and human shields, and there were no heavy air strikes in urban residential neighborhoods. Combat operations were short and apart from the three or four days of looting, violence in the post-conflict phase was low. Putting all these factors together, Panama appears to be a scenario where both the magnitude of civilian casualties was relatively low and the demographic makeup of those casualties was skewed towards adult men.

Age and gender breakdown for civilian deaths in Somalia are not available and it is more difficult to talk of exposure for women and children. However, one would expect a higher proportion of deaths among women and children for several reasons. In Somalia, both women and children actively participated in the fighting and acted as human shields for militia and irregular Somali fighters. This would clearly bring them more frequently into the line of fire and in many cases make them legitimate targets. Throngs of Somali civilians, including women, children, and the elderly, also ran towards the sound of gunfire and congregated at the scene of gun battles. This would also have increased the percentage of women and children victims, compared to Panama, by increasing casualties from crossfire. Another aspect that made operations in Mogadishu different from those in Colon and Panama City was the amount of control that U.S. forces had over events. In Panama, it seems fair to characterize U.S. forces as generally in control of the situation. In Somalia, the gun battle was far fiercer than what troops had prepared for and the situation was far more desperate than what it had been in Panama City or Colon. It is not implausible to argue that troops facing such conditions are less likely to have the time to better distinguish between potential targets.

Operations in Iraq offer a more mixed picture. As discussed in the case studies, women and children reportedly made up 18% of deaths during major combat operations and the first two years of reconstruction. Major combat operations in Iraq appeared to put women and children in danger. As discussed earlier, air strikes against leadership targets tended to fall in residential neighborhoods. Intense urban warfare also appeared to put women and children in danger by bringing violence into residential areas. On the other hand, adult Iraqi men appeared to be the most frequent victim of violence during OIF.[208] The overall lower rate of death for adult Iraqi women over the entire conflict is consistent with reports that women restricted their travel – and thus their exposure to danger in many instances – after the fall of Saddam Hussein's government.

To summarize the discussion, a high percentage of women and children in a city do not automatically translate into a high percentage of female and child civilian deaths during an urban operation. Such deaths appeared to have been mitigated in Operation Just Cause. However, not all urban campaigns will experience conditions as favorable for limiting these types of casualties and in some cases the higher population numbers do translate into higher casualty numbers. As women and children willingly or unwillingly become human shields, as other factors draw them more frequently into the line of fire, as residential buildings receive heavy fire, and as U.S. forces have less time to distinguish between likely targets, they inevitably become a higher portion of those killed. The higher percentage of children in a developing country's population should become increasingly represented among the civilian dead as these types of circumstances prevail.[209]

Besides demographic heterogeneity, another type of heterogeneity is uneven population distribution. The previous section of this chapter began with a non-combatant population that was uniformly distributed across a large area. In actuality, people are distributed unevenly across a city. Some areas of a city and some buildings within a block are more densely occupied than others. One would expect to see greater heterogeneity in density for more developed cities such as Panama City and Baghdad because of the presence of high-rise buildings and greater differentiation in use of urban spaces. At the same time, even lesser developed cities such as Mogadishu will have areas of higher population

[208] Iraq Body Count, p. 2.

[209] Another issue has to do with the potential impact of realistic demographics has to do with non-lethal weapons. Non-lethal weapons are currently being developed, tested, and modeled in computer simulations. However, it would be prudent to keep in mind that non-lethal weapons may be deadlier for certain segments of a population, such as for children and the elderly. The high percentage of children in some populations should not be forgotten as theory and practice for the use of these weapons evolves.

density. Figure 4-5 below gives an idea of the difference in building density between neighborhoods:

Figure 4-5. Aerial Photograph of Mogadishu

Source: Space Imaging and GlobalSecurity.org.

One consequence of heterogeneous population distribution is that there may be events that produce an unusually large number of civilian deaths. For example, the bombing of the al Firdos bunker that turned out to be filled with civilians during the 1991 Gulf War was an event where a bomb struck a point in the city that was densely populated at that moment. The incident had a major impact on the subsequent conduct of the air war and such events are likely to happen again in future conflict in urban areas. Although this would not be evident in a model using a uniform population density, this type of differentiation is easy to add. Heterogeneity in population density will also result in heterogeneity in the non-combatant to combatant ratio throughout a city. This is a realistic reflect of actual urban operations, where troops on the ground must operate in some areas that are more crowded than others.

In modeling, assigning different population densities throughout a simulated city would allow for the possibility of catastrophic civilian casualty incidents. Such a density distribution could even be generated randomly instead of based on an actual city. Random generation of many non-combatant parameters in a model may give more interesting results than attempting to base them on any particular past operation or incident. Not only is this easier, it has the advantage of offering combinations of parameters that were possible but that did not happen to occur in that incident. Because particular events in history may be so specific to that event and are unlikely to be recreated in the future, exploring the space of possibilities may be a better use of analytic resources than attempting to recreate the specific conditions that were present at the time. Related to heterogeneity in population distribution is heterogeneity in the "hardness" of urban cover. Across cities and even within the same city, there will be some buildings and urban structures that offer better shielding for non-combatants. Concrete buildings offer better protection to inhabitants than shantytown buildings with tin roofs. Varying both the population density and the protection factor across a city introduces the potential for very unexpected events in a model. It is a simple way to create the pockets of vulnerable civilians within a model that are found in real urban operations.

Another type of heterogeneity that may be interesting to add when non-combatant actors in a model have interactive behavior. This is heterogeneity by ethnic group, clan, class, or faction. Casual observation would appear to support the implication of Schelling's model for self-segregating neighborhoods: people do tend to sort by ethnicity, clan, and other divisions in real life rather than being distributed randomly across a given area. Alternatively, one may argue that people within the same geographical area are more likely to share common loyalties, political interests, kinship ties, and other attributes. The implication is that there may be pockets of people within a city or within a country that are more or less friendly to U.S. forces. In Colon, poorer neighborhoods were often less friendly to U.S. troops. In Somalia, members of Aidid's clan were concentrated in certain areas. In Iraq, there were pockets of anti-American discontent in Tikrit, Najaf, and Fallujah. It would be very realistic to have pro- or anti-U.S. civilians grouped together in a simulation, creating areas of helpful or hostile activity for blue forces.

Changes Over Time

There are a few things to be said about changes to population density and heterogeneity over time. To begin with, there are long-term trends over years and decades that are of general or long-term interest but that have limited immediate operational relevance and little meaning within the context of modeling non-combatants. These types of trends include increased urbanization in many countries, both through migration and natural population increase. In the long run, many developing countries also experience declining birth rates and longer life expectancies. This would decrease the proportion of children in an urban area but perhaps increase the elderly population. Another trend is the overall population increase in many developing areas of the world. This would also lead to higher population densities for many cities in the future. While this may have implications for strategic thinking about future urban operations and future population densities, these types of changes are still many steps removed from analysis that directly affects day-to-day urban operations. Because the timelines involved are beyond the timeline of most urban simulations, these types of trends are also unlikely to be useful for most modeling applications.

Population density changes over a shorter time scale have more immediate operational effects and may be fairly easily incorporated into models. These are changes over days, weeks, or months. (Changes to population density on a shorter time scale, such as minutes or hours, are better dealt with in the following chapters on non-combatant behavior and movement.) Migration of refugees or internally displaced persons into an area has implications for the management of humanitarian, peacekeeping, stability, or counterinsurgency operations. Increasing the population density in an area increases manpower requirements for U.S. forces engaged in peacekeeping and SOSO in that given area. There is also greater concern for the civilian population being used for concealment and cover by combatants during an insurgency. Short-term population density changes may also work in the opposite direction, with people leaving an area during the course of operations. For example, by November 2004, most of Fallujah's 200,000 to 300,000 residents had fled the fighting between insurgents and U.S. Marines.[210]

It is also possible for U.S. troops to manage changes in population density to their advantage. In many situations they may be able to influence density by warning non-combatants to leave, establishing humanitarian aid centers in certain locations, or blocking off travel so other areas. There is also room to manage the exposure that non-combatants may face over short periods of time, such through curfews or other methods to encourage civilians to stay indoors or to avoid certain areas. Cutting off power and water to an area is another tactic that can encourage civilians to leave. Actively managing civilian exposure to urban operations is a means to reducing civilian casualties and

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[210] Associated Press, "U.S.-led Forces Begin Second Phase of Falluja Offensive," November 11, 2004.

denying cover to enemy combatants who are using civilian populations for cover and concealment.

Example: Civilian Casualty Model

The following civilian casualty model illustrates how population density can be used to estimate casualties from air strikes in a populated urban area. Specifically, the model attempts to assess how many civilian casualties should have been expected from the 2003 leadership strikes during OIF. U.S. forces conducted over 50 time-sensitive missions aimed at killing various Iraqi leaders during major combat operations.[211] As information surfaced about the possible whereabouts of Saddam Hussein and other top Baath Party officials, U.S. forces bombed these suspected hiding places. The majority of these leadership strikes appeared to have been in residential neighborhoods around Baghdad and resulted in civilian deaths. Human rights groups criticized the United States for using unreliable intelligence methods to determine strike locations, for failing to do collateral damage assessments before these strikes, and for generating civilian casualties while missing every individual they targeted.[212] In contrast, preplanned missions against Iraqi military and government targets resulted in fewer civilian casualties because civilians generally did not have access to these locations.[213] U.S. planners also had more time to evaluate possible civilian deaths for preplanned strikes and avoided targets that would have resulted in a large number of civilian deaths.[214]

Although the time-sensitive nature of these leadership strikes did not allow enough time for U.S. forces to evaluate the impact on nearby civilians, using the average population density of Baghdad would have given an approximation for the number of civilians killed in each strike. Because these strikes tended to be in residential areas, there would have been civilians present. There is the argument that precision-guided munitions should result in fewer civilian deaths than "dumb" bombs, and that basing civilians deaths on the city's average population density does not take this into account. However, even with the use of laser- and Global Positioning System (GPS)- guided bombs, expected

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[211] Moseley, p. 9. The U.S. Air Force conducted 50 such missions. The U.S. Navy also launched an unspecified number of ship- and submarine-launched cruise strikes at Iraqi leadership targets.

[212] Human Rights Watch, *Off Target: the Conduct of the War and Civilian Casualties In Iraq,* pp. 6, 22-4.

[213] Human Rights Watch, *Off Target: the Conduct of the War and Civilian Casualties In Iraq,* pp. 41-2.

[214] Schmitt, p. B12.

civilian casualties may still be estimated as if these munitions struck a populated area. There are two reasons why.

First, even if targeting coordinates were perfectly precise, the accuracy of U.S. bombs is moot when the lethal radius of a warhead for civilians and civilian buildings is much larger than the CEP. Put another way, even if a bomb hits a targeted building exactly at the desired spot, the force of the explosion may be enough to damage or destroy the building next to it. In the residential neighborhoods such as those where these OIF leadership strikes took place, some number of surrounding homes next to a targeted home would be damaged or destroyed. Thus the population density in a given city or neighborhood and the lethal radius of a bomb factor heavily into the resulting number of civilian casualties.

Second, the population density around these leadership targets was more representative of population density across Baghdad than would be true for preplanned targets. For preplanned targets, U.S. military planners had time to assess potential civilian casualties and to avoid targets where there was a high density of non-combatants. This would mean that preplanned targets were in lower population-density areas of Baghdad and other cities. On the other hand, leadership strikes were launched as intelligence came in – at times within minutes of receiving information.[215] There was no time to assess the potential effects on civilian casualties and no way of knowing beforehand where these targets would be. In short, leadership strikes were more likely to end up in populated areas than preplanned ones.

A simple way to estimate the civilian casualties expected from a given bomb landing in a residential neighborhood is to take the area affected by the bomb and multiply it by the density of people per unit of area. Letting the *effects radius* be the distance from the center of an explosion within which people will be killed:

$$\textit{Civilian Casualties} = (\pi \cdot \textit{Effects Radius}^2) \cdot (\textit{People/Unit Area})$$

Next, the effects radius of a warhead is a function of two things: 1) the vulnerability of the target to its effects; and 2) the magnitude of a warhead's

[215] David C. Isby, "Coalition Makes Massive Use of Guided Munitions," *Jane's Missiles and Rockets*, May 1, 2003; and Kim Burger, Nick Cook, Andrew Koch, and Michael Sirak, "What Went Right?" *Jane's Defence Weekly*, April 30, 2003.

effects at a given distance.[216] Looking at blast effects, there are two different types of pressure generated by an explosion: peak overpressure and dynamic pressure. For human beings standing out in the open, there is a 50% chance of lethality (probability of kill $P_k = 0.5$) when the peak overpressure for an explosion is between 33 and 58 psi.[217] A person standing 27 meters from a 1,000-lb TNT-equivalent explosion or less than 22 meters from a 500-lb explosion is almost certain to sustain severe injury or death.[218] People are able to improve their chances of survival by lying prone, taking cover, and otherwise shielding themselves from the blast.[219]

People also die when explosions collapse buildings. Civilians in residential areas are likely to be inside their homes and many deaths are presumably caused when residential buildings collapse. This is especially true when such strikes are carried out mostly at night, as with the OIF leadership strikes. A building's vulnerability depends on several factors, including construction material and height. Rigidly constructed buildings are less likely to survive a given peak overpressure than buildings that can flex or adjust.[220] Table 4-6 below gives the distance from an explosion where a given type of building will suffer frame collapse and massive destruction. Note that unreinforced concrete masonry buildings, potentially common in some areas of the developing world, are particularly vulnerable.

Table 4-6. Distance From Explosion Where Building Experiences Frame Collapse or Massive Destruction

TNT Equivalent Weight of Explosion	Reinforced Concrete Masonry Building	Large One-Story Wooden Building	Unreinforced Concrete Masonry Building
500 lb	3 m	12 m	30 m
1,000 lb	2 m	21 m	46 m

Source: Lim. Estimated distances where buildings would be over 60% damaged.

216 A target may also be vulnerable to the fragmentation from certain types of munitions. For this example, we assume that the types of munitions used in leadership strikes do the bulk of their damage through blast effects.

217 R. Augustus Lim, *Anti Terrorism and Force Protection Applications in Facilities* (University of Florida, Department of Civil and Coastal Engineering, 2003), p. 10. This figure reflects lethality from blast effects and does not factor in potential fragmentation effects.

218 Lim, p. 10.

219 Fragmentation effects from explosions may also result in casualties. However, the munitions used in these types of airstrikes are not primarily intended to be fragmentation weapons.

220 Lim, p. 9.

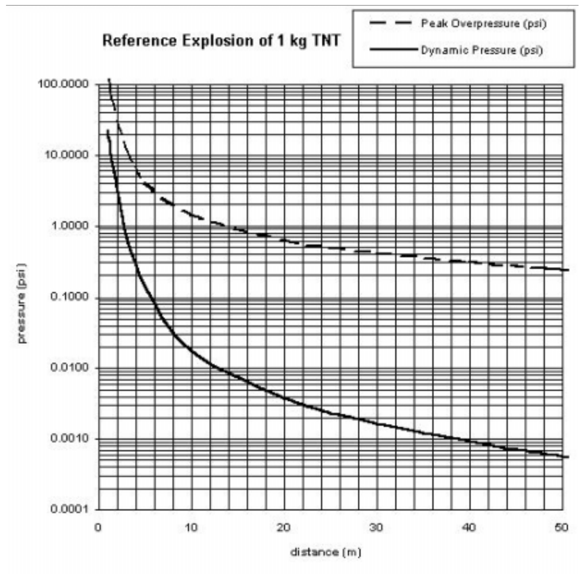
Figure 4-6. Expected Building Damage from Blast Overpressure

Damage	Incident Overpressure (psi)
Typical window glass breakage	0.15 – 0.22
Minor damage to some buildings	0.5 – 1.1
Panels of sheet metal buckled	1.1 – 1.8
Failure of concrete block walls	1.8 – 2.9
Collapse of wood framed buildings	Over 5.0
Serious damage to steel framed buildings	4 – 7
Severe damage to reinforced concrete structures	6 – 9
Probable total destruction of most buildings	10 – 12

Source: FEMA, 2003.

Figure 4-6 above gives the type of building damage that can be expected at different levels of peak, or incident, overpressure. Presumably unreinforced concrete masonry walls will fail from about 2 psi, reinforced concrete buildings will be severely damaged from 6 psi, and most buildings will likely be destroyed from 10 psi upwards. What is important to note is that these are lower than the overpressures that are fatal at least half the time for people who are out in the open (33+ psi). With this data on target vulnerabilities, the second piece of information that is required to calculate the effects radius of a munition is the size of the warhead. Data on the actual blast effects of various U.S. munitions are classified. However, it is possible to estimate the peak and dynamic overpressure at a given distance from an explosion based on the weight of a high explosive (HE) warhead. This is done by basing estimates on a reference explosion of 1 kg of TNT:

Figure 4-7. Blast Effects From a 1 Kg TNT Explosion



Source: Federation of American Scientists

If a 1-kg TNT explosion produces a given peak overpressure at distance d_o from the center of the blast, an explosion of W kg of TNT will produce that peak overpressure at distance d_W according to the following scaling law:[221]

$$d_W = d_o W^{1/3}$$

Although not all the details of air war during OIF are yet available, the use of the following munitions in "decapitation" strikes against the Iraqi leadership has been reported in the press:

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221 John Stillion and David Orletsky, *Airbase Vulnerability to Cruise-Missile and Ballistic-Missile Attacks* (Santa Monica, CA: RAND Corporation, 1999), pp. 12, 63-4; and Federation of American Scientists, "Introduction to Naval Weapons Engineering: Warheads," Internet: accessed at http://www.fas.org/man/dod-101/navy/docs/es310/warheads/Warheads.htm on February 2, 2005.

Table 4-7. Munitions Used Against OIF Leadership Targets

Munition	Weight	Terminal Guidance	CEP
GBU-12 Paveway II	500 lb	Laser	8 meters
Tomahawk (Block III)	1,000 lb	DSMAC and GPS	6-10 meters
EGBU-27	2,000 lb	GPS and Laser	N/A
GBU-31 JDAM	2,000 lb	GPS	13 meters

Source: Burger, et. al., Isby, Jane's Information Group, Federation of American Scientists.

It should be noted that a 500-lb bomb carries less than 500 lbs of explosives because some of the weight is taken up by navigation, guidance, and other components. Additionally, not all munitions use TNT. Although Figure 4-6 provides data to estimate the effects of TNT payloads, many U.S. munitions use explosives that are many times more powerful than TNT. To arrive at an approximate number of casualties from these leadership strikes, the calculations below assume that 45% of a warhead's weight is explosive and that the explosive is equivalent to TNT. (It should be clear that this estimate is low if other types of explosives were used in the actual strikes.) With approximate payload weights, casualty estimates based on different effects radius assumptions are now possible. For any given peak overpressure, Figure 4-7 provides the distance d_o in meters at which this overpressure occurs for a 1-kg ton explosion.

If residential buildings collapse at 6 psi, civilian casualties with occur within a wider radius than if buildings collapse at 10 psi. Converting the estimated payload W_{lb} from pounds into kilograms (W_{lb} is 45% of the total warhead weight), the effects radius in meters associated with a specific peak overpressure is given by:

$$\textit{Effects Radius} = d_o\,(W_{lb} \cdot 0.45\ \text{kg/lb})^{1/3}$$

This effects radius does not have to be the distance where death is certain ($P_k = 1.0$). However, it is plausible to use a "cookie cutter" approach to estimating casualties by assuming complete lethality within the effects radius and no damage outside this radius.[222] This is because while not everyone inside a given radius will be killed, some outside this radius will be. For example, assume that a certain type of building has a fairly high but less than 100% probability of collapsing at 10 psi peak overpressure. An explosion may destroy most of the building and kill most of its inhabitants within this 10 psi distance. However, similar buildings standing farther from the explosion may also experience some damage and bear some fatalities, even though these buildings

[222] Stillion and Orletsky, pp. 62, 64.

only experienced 8 or 9 psi. For the purpose of obtaining a ballpark number of deaths, it is then plausible to estimate deaths as if everyone inside the first building would be killed and nobody in buildings farther away were harmed.

The earlier discussion in Chapter 4 estimated a population density of 31,600 people per square mile for Baghdad in 2003 during OIF, which is equivalent to 0.001133 people per square foot. Converting this lethal radius from meters to feet and calculating the area cover by this distance yields the expected number of civilian deaths from a given air strike:

$$\textit{Civilian Casualties} = (\pi\ (\textit{Effects Radius} \cdot 3.28\ \text{ft/m})^2) \cdot (0.001133\ \text{people/ft}^2)$$

Table 4-8. Estimated Civilian Deaths Under Different Effects Radius Assumptions

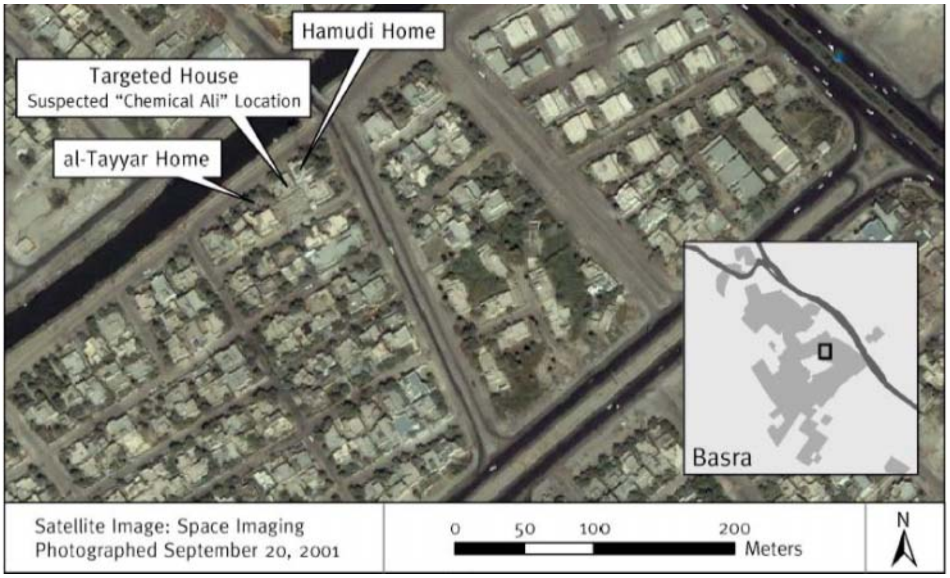
Notional Warhead*	Effects Radius (m)			Estimated Civilian Deaths		
	2 psi	6 psi	12 psi	2 psi	6 psi	12 psi
500 lbs	140	19	14	754	13	8
1,000 lbs	177	24	18	1,197	21	12
2,000 lbs	223	30	22	1,900	34	19

*Table 4-7 assumes 45% of a warhead's weight to be TNT-equivalent explosive.

From the assumptions in this exercise, expected fatalities from a single strike could range from about 8 to 1,900 depending on building construction and warhead size. There are more estimated civilian deaths when the size of the warhead increases and when the effects radius is larger. (For example, the effects radius would increase where buildings are more vulnerable. This would mean that buildings collapse at a lower peak overpressure.) Again, the peak overpressures used in Table 4-8 were from data on estimated building damage in Figure 4-6. 2 psi is the overpressure at which unreinforced concrete masonry walls will fail; 6 psi presents the point where reinforced concrete structures begin to experience severe damage; and 10-12 psi is the range where most buildings will be completely destroyed.

Do the overpressure values used in Table 4-8 reflect the approximate effects radii for leadership air strikes in OIF? One way to test is to examine the damage done during an actual strike. Figure 4-7 below shows satellite imagery from the leadership strike against Lieutenant General Ali Hassan al-Majid ("Chemical Ali") on April 5, 2003 in Basra:

Figure 4-8. Satellite Image of Leadership Strike in Basra



Source: Human Rights Watch

Two homes, belonging to the Hamudi and al-TaAyyar families, were destroyed. According to witnesses, there were two bombs: one that hit a neighboring road and one that hit the target and destroyed two surrounding houses. The munition that did hit the target was thought to be a 500-lb LGB.[223] Looking at the image, these two homes were within 20-25 meters of the target. Additionally, 17 out of 22 civilians (77%) inside these two homes died, including nine children under age 15 (53% of deaths in this incident). This 20-25 range is about the range from a 6 psi effects radius. Assuming similar building construction in Basra and Baghdad, this appears to be a reasonable effects radius to use for Baghdad as well.[224]

The next portion of this example turns to discussing the probabilistic uncertainty in some of these estimates. Table 4-8 displays the mean (μ) – the expected value of civilian deaths under the assumptions outlined above. If these strikes are thought of as a Poisson-distributed statistical process, it becomes possible to find the variance (σ^2) as well. The Poisson distribution can serve as an approximation for the binomial distribution when the number of trials *n* is

[223] Human Rights Watch, pp. 28-32.

[224] The actual number of fatalities from this particular raid cannot be compared with the estimates in Table 4-8 because the population density of Baghdad is different from the population density of Basra.

large and the probability p of a certain event is small. With n representing the number of civilians in Baghdad and p representing the probability that any individual will be killed in a leadership strike, n and p are such that the number of civilians killed in a single strike may be considered Poisson. One of the properties of the Poisson is that the mean is equal to the variance. Hence, the mean and variance for the number deaths from one strike using a 500-lb bomb and assuming a 6 psi effects radius are both 20.[225] It is also possible to arrive at the probability that a single strike under these assumptions will yield more than 30 civilians deaths, the threshold during OIF for requiring that the Secretary of Defense approve a target.[226] Letting X be the number of deaths and $\lambda = \mu = 13$:[227]

$$P\{ X = i \} \approx e^{-\lambda} (\lambda^{i}/i!)$$

Thus:

$$P\{ X > 30 \} = 1 - P\{ X = 1 \} - P\{ X = 2 \} - \ldots - P\{ X = 30 \}$$

$$\approx 1 - e^{-\lambda} (\lambda) - e^{-\lambda} (\lambda^{2}/2) - \ldots - e^{-\lambda} (\lambda^{30}/30!)$$

$$\approx 1 - e^{-23} (13) - e^{-23} (13^{2}/2) - \ldots - e^{-23} (13^{30}/30!) = 0.000016$$

The calculation shows that there close to a 0% probability that the use of a 500-lb bomb in a neighborhood of one of buildings that could withstand up to 6 psi peak overpressure would kill more than 30 civilians.

However, if residential buildings cannot withstand more than 2 psi, then this probability will change. Estimating the damage that a 500-lb bomb would do in this case uses the same calculation above, but with $\lambda = 754$ instead of 13 from Table 4-9. This gives $P\{ X > 30 \} \approx 1.00$. In short, there is a 100% chance that an air strike under these assumptions would kill more than 30 people. Such a strike would likely have required approval from the Secretary of Defense if normal collateral damage assessment procedures had been followed. Table 4-10 shows the probability of killing more than 30 people using various assumptions:

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225 Sheldon M. Ross, *Introduction to Probability and Statistics for Engineers and Scientists*, International Edition (New York: John Wiley & Sons, 1987), pp. 78-89.

226 Bradley Graham, "U.S. Moved Early for Air Supremacy," *Washington Post*, July 20, 2003, p. A26.

227 Euler's number $e \approx 2.7183$.

Table 4-9. Probability of More than 30 Civilian Deaths From a Single Strike

Notional Warhead*	Peak Overpressure At Which Buildings Collapse		
	2 psi	6 psi	12 psi
500 lbs	100%	0%	0%
1,000 lbs	100%	3%	0%
2,000 lbs	100%	71%	1%

The implication of Table 4-9 is that construction practices in a given area of the world have as much effect on exceeding this 30-death threshold as does weapons choice. For example, where buildings are predominately built from unreinforced concrete masonry (2 psi level), there will be significant casualties even when using the smallest warheads available. On the other hand, in a city of reinforced concrete buildings (6 psi level), only a strike using the largest warhead would have required Secretary of Defense approval under normal circumstances.

The discussion now turns to the total numbers of civilians potentially killed from the entire leadership strike campaign. Table 4-8 estimated civilian deaths from a single air strike. Table 4-10 below estimates a lower and upper range for the number of deaths that could be caused from 50 such air strikes, assuming a 6 psi effects radius. (There were at least 50 such strikes during OIF). It also estimates how many of these deaths might be expected to be children, given Iraq's demographics. The table also assumes that all 50 strikes were carried out by one type of munition and that only one warhead was dropped on each target. In reality there would be a mix of munitions and perhaps more than one warhead per strike. Still, Table 4-10 provides a possible range for the number of civilian deaths that could have resulted from these leadership strikes:

Table 4-10. Estimated Civilians Deaths From 50 Leadership Strikes

Notional Warhead*	Deaths In One Strike	Deaths From 50 Strikes	Deaths Under Age 15 From 50 Strikes**
500 lbs	13	670	275
1,000 lbs	21	1,064	436
2,000 lbs	34	1,689	692

*Assumptions: a 6 psi effects radius and 45% of a warhead's weight to be TNT-equivalent explosive.
**Children under age 15 represented 41% of Iraq's population in 2003.

Table 4-10 suggests that even using only a single 500-lb bomb (the smallest LGB in the U.S. arsenal) per sortie, 50 leadership strikes in populated areas would result in several hundred dead civilians. Given Iraq's population pyramid, some 275 of these dead would be children under age 15. Other factors would increase this estimated number of total civilian deaths. First, as the weapons mix changes to include larger bombs and as the number of bombs per sortie increases, the expected number of civilian deaths climbs. U.S. forces did predominately use 500-lb LGBs in Baghdad to reduce collateral damage and not all leadership strikes took place in populated areas.[228] However, there were times when the United States used 1,000- and 2,000-lb warheads in areas where civilians were present. Second, the calculations in this estimate use average population density across Baghdad. The number of civilian deaths would increase if true population densities in the areas where U.S. forces typically conducted leadership strikes is higher than this average. (The estimates in Table 4-8 and Table 4-10 represent the expected number of deaths if nothing is known about how these local population densities might vary.)[229]

If the United States believes it will carry out time-sensitive strikes in residential areas again in the future, it should develop very small payload PGMs. Table 4-10 below looks at how 100-lb PGMs might reduce casualties over 500-, 1,000-, and 2,000-lb bombs used in a city with the population density of 31,600 people per square mile:

Table 4-11. Expected Reduction in Civilian Casualties From Using 100-lb PGMs

Notional Warhead*	Effects Radius (m)		Expected Deaths From 50 Strikes		% Reduction in Deaths If 100-lb PGMs Used	
	6 psi	12 psi	6 psi	12 psi	6 psi	12 psi
100 lbs	5	3	229	129	--	--
500 lbs	13	8	670	377	66%	66%
1,000 lbs	21	12	1,064	598	78%	78%
2,000 lbs	34	29	1,689	950	86%	86%

*Table 4-10 assumes 45% of a warhead's weight to be TNT-equivalent explosive.

228 Isby.

229 In actuality, there is little data on the number of civilians actually killed during leadership strikes in OIF. U.S. authorities no longer make estimates on the number of non-combatants killed during military operations. Additionally, uman rights groups often provide reports on deaths from individual incidents (Human Rights Watch) or track estimated deaths from the conflict as a whole (Iraq Body Count). However, no group has offered reports or estimates on the number killed specifically as a result of the 50+ leadership strikes. Even when groups attempt to document or publicize deaths from individual leadership strikes, they are not likely to know which air strikes were aimed at Iraqi leaders as opposed to other types of targets. Hence, they would be unable to provide an accurate tally of death due strictly to leadership strikes.

Using a 100-lb PGM instead of a 500-lb one would cut civilian deaths by 66% under these set of assumptions. As Table 4-11 shows, this 66% reduction is independent of the effects radius: there will be the same percentage decline in expected deaths whether a munition kills civilians within a 6 psi area or a 12 psi area. This reduction should also be independent of population density as well: there will also be the same percentage reduction whether the population density is 31,600 people per square mile or 60,000. This is because in calculating the percentage decrease in casualties, the same population density number is in both the numerator and the denominator. To illustrate this point, let q_0, the number of expected civilian deaths from a warhead, be a function of the payload W_0 (kilograms), a given effects radius r (meters), and the population density ρ (people per m^2). The area affected by the warhead is a function $f(W_0, r)$. Thus:

$$q_0 = f(W_0, r)\cdot\rho$$

The number of expected civilian deaths from a warhead with a different payload W_1 is:

$$q_1 = f(W_1, r)\cdot\rho$$

The decline in civilian deaths moving from W_0 to W_1 is:

$$\textit{Percentage Change in Expected Civilian Deaths} = (q_1 - q_0) / q_0$$

$$= [f(W_1, r)\cdot\rho - f(W_0, r)\cdot\rho] / [f(W_0, r)\cdot\rho]$$

$$= [f(W_1, r) - f(W_0, r)] / f(W_0, r)$$

Therefore the population density cancels out and the percentage change in expected civilian deaths is a function of warhead payloads for a given effects radius.

Given the magnitude of possible reduction in expected civilian deaths, Table 4-11 would seem to support the case for developing smaller PGMs.[230] As a further test of whether it does support such a policy, the next question is whether or not such a reduction in civilian deaths could happen merely due to chance if there was no change in the warhead size used in these strikes. At the 6

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[230] In a few past incidents, the USAF has used what are effectively concrete warheads instead of HE warheads in an attempt to minimize collateral damage. However, these attempts did not tend to work out well because a concrete block dropped from moving planes tend to keep moving laterally after it has struck its initial aim point. This causes damage outside the target area as the concrete continues to move and strikes objects at a very high velocity. In contrast, a properly functioning HE warhead should detonate upon impact and destroy itself. See Russell W. Glenn, Christopher Paul, and Todd C. Helmus, *Men Make the City: Joint Urban Operations Observations and Insights from Afghanistan and Iraq* (Santa Monica, CA: RAND Corporation), forthcoming.

psi effects level, the expected number of deaths from 50 strikes using 100-lb warheads is 229 and the expected number of deaths from using 500-lb warheads is 670. It has been discussed how the number of deaths from any single strike is distributed Poisson. Another property is that the sum of Poisson distributions is also Poisson.[231] Knowing this allows a test of whether or not using 100-lb bombs would reduce the number of civilian deaths in a statistically significant way. Let X represent the number of civilian deaths, this time from 50 leadership strikes and with the expected number of deaths $\mu = \lambda = 670$. The probability that using 500-lb bombs would result in no more than 229 deaths is:

$$\begin{aligned} P\{X \leq 229\} &= P\{X = 1\} + P\{X = 2\} + \ldots + P\{X = 229\} \\ &\approx e^{-\lambda}(\lambda) + e^{-\lambda}(\lambda^2/2) + \ldots + e^{-\lambda}(\lambda^{229}/229!) \\ &\approx e^{-670}(670) + e^{-670}(670^2/2) + \ldots + e^{-670}(670^{229}/229!) \\ &\approx 7.0 \times 10^{-87} \approx 0 \end{aligned}$$

It is statistically impossible for a 500-lb bomb to cause the same number of deaths as a 100-lb bomb. Thus, using 100-lb bombs would reduce deaths to a level that would never be seen using the larger warheads. There is already support to add smaller warheads to the U.S. arsenal. U.S. forces in Afghanistan and Iraq expressed the view that 2,000-lb JDAMS were too big in some situations, calling instead for 50- and 100-lb JDAMS, and even for munitions where the size of the payload could be adjusted.[232]

This example shows how analysis using population density can have practical implications for certain types of simple policy questions. The OIF leadership strike example shows that such analysis has relevance for weapons choice, development, and usage in urban areas. It uses a simple method for arriving at a rough estimate of civilian deaths when there is a lack of detailed information or little time to gather data for a better assessment. The example also serves as a baseline for asking other questions about ways to decrease civilian casualties from leadership strikes, such as policies to change the population density in a city.

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231 Ross, p. 83.

232 Russell W. Glenn, Christopher Paul, and Todd C. Helmus, *Men Make the City: Joint Urban Operations Observations and Insights from Afghanistan and Iraq* (Santa Monica, CA: RAND Corporation), forthcoming.

5. Simple Non-combatant Behaviors

Chapter 5 deals with simple non-combatant behaviors. After population density, background behavior and simple reactions to combat are the next layer of non-combatant behaviors. The case studies reveal a number of simple behaviors that appear often across individuals and across cases. The previous chapter argued that merely introducing realistic population densities was an analytically useful exercise that could improve understanding on several types of policy and operational issues. Chapter 5 extends this approach by exploring the usefulness of considering basic non-combatant background movement and simple reactions to combat. The chapter builds on the previous discussion on populating models and adds the context for complex non-combatant behavior discussed in the next chapter. Simple behaviors are also often a prelude to more complex ones, as will be seen in Chapter 6.

The first section of this chapter discusses the relevance of taking simple non-combatant behaviors into consideration. The next section discusses background behaviors that exist in any urban area: commuting, congregation, and traffic. The third section introduces simple reactions to combat: running away from combat, seeking shelter, ignoring combat, and running towards it. The next section of Chapter 5 discusses modeling implications of the simple behaviors outlined in this chapter within the framework of agent-based modeling. The last section offers an example of how having a model that incorporates simple non-combatant behaviors might provide policy insights not available with a static population.

Adding Simple Movement

Many envision the advanced, complex, and adaptive behavior that civilians can show in confrontations with U.S. troops when they first begin to contemplate non-combatant behavior. However, beginning with simple non-combatant behavior is an analytically useful step for a number of reasons. First, these simple behaviors do account for many of the combatant-civilian interactions that U.S. forces have faced on the ground. There are a number of policy and operational issues that arise from these interactions. For example, commuting and congregation lead to U.S. troops encountering non-combatants on roads and marketplaces; civilian traffic creates cover for disguised combatant vehicles; and U.S. troops meet civilians running and seeking shelter in the middle of urban gunfights. All of these simple non-combatant behaviors have implications for rules of engagement, civil affairs, and public relations.

Second, simple non-combatant behavior is also important because it is exhibited more often by more of the civilian population than some of the most complex behavior. Some of the most complex behavior might be limited in frequency or scope. For example, widespread looting matters a great deal when it occurs, but it does not always happen. Civilians attacking U.S. forces is also behavior that causes concerns, but it may be limited to a subset of civilians under certain situations. There is no doubt that these complex behaviors can have dramatic impacts on the conduct and outcome of U.S. military operations. However, simple behaviors such as running away from gunfire or accidentally driving through combat areas is much more universal behavior. The point here is that some of these uncomplicated and unspectacular behaviors happen more of the time during an urban operation and are still worth preparing for because of their frequency.

Third, it may also be sufficient for some purposes to stop at the simple non-combatant behavior that is discussed in this chapter. This may be true particularly when considering a scenario where non-combatants are predominantly neutral or friendly to U.S. forces and are not likely to actively interfere in operations, such as Panamanian civilians during Operation Just Cause. To get a general sense of civilian behavior during a short operation in a fairly friendly environment (excluding looting), the primary behaviors to focus on are background movement and defensive reactions to combat.[233] In either live training exercises or computer simulations, limiting the scope of non-combatant action to these behaviors would be sufficient for dealing with a friendly-population scenario. Using the simplest set of rules possible to recreate realistic behavior is also consistent with the art of simulation. Striving for simplicity in design – even when the expected output is complex – results in a model that is more elegant: assumptions that are more transparent, output that is easier to understand, and a structure that sets a cleaner baseline for more complicated analysis.

Fourth, simple non-combatant behavior can affect population density, with all the implications discussed in the previous chapter. Background

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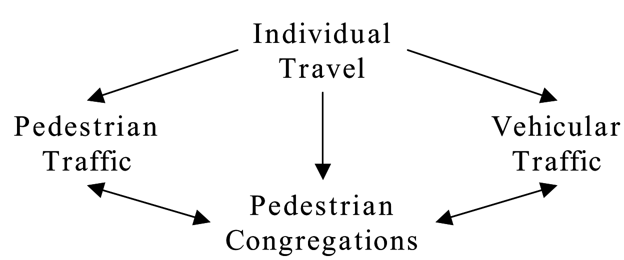
[233] Although there were a few reports of Panamanian civilians attacking U.S. forces, these appeared to be isolated incidents. They did not happen frequently enough to change the overall non-combatant environment or to warrant a systematic assessment of the way U.S. troops interacted with civilians.

behaviors such as travel and congregation produce dynamic changes to population and vehicle density. Congregating behavior in particular will tend to produce population density patterns over time that can matter during urban operations. For example, congregation in areas such as markets produce crowds of civilians who can be used for cover or who can be targeted by insurgency forces, as in Iraq. Simple reactions to combat (running away, etc.) produce less predictable changes in population density but are also capable of producing sudden, significant changes in local density at the scene of urban fighting. For example, these behaviors can produce crowds, disperse crowds, alter the density of non-combatants in nearby buildings, generate traffic, or create other non-combatant movement at that location.

Background Movement

The mere presence of civilians, their background movement, and their reactions to combat increase the clutter and confusion that U.S. forces must deal with on the urban battlefield. This section discusses background non-combatant movement – travel and congregation – while the next section deals with simple reactions to combat. The sheer number of traveling, commuting, and congregating civilians in an urban area, combined with the fact that many may be caught in these activities when U.S. forces enter a city, mean that it is important to consider the implications of these behaviors. Background movement appears to be the reason that many non-combatants end up as casualties in conflicts, leading them to be inadvertently in the wrong place at the wrong time. Traveling, either by foot or with vehicles, leads to three behavioral phenomena: pedestrian congregations in buildings and in streets, pedestrian traffic, and vehicle traffic throughout a city:

Figure 5-1. Background Behaviors



One of the normal, daily activities that people undertake is commuting and traveling from their homes to workplaces, schools, stores, markets, and places of worship. There are many reasons why this seemingly mundane behavior is of interest. First, civilians traveling during urban fighting run the risk of becoming casualties. The Panama and Iraq case studies show that many civilians became casualties while they were traveling, particularly in vehicles.[234] Any genuine attempt to limit non-combatant casualties during urban operations begins with realization that a city's traveling residents are likely to be exposed.

Second, civilian vehicle traffic provides both concealment and cover for unconventional forces operating within their midst. It provides concealment by allowing unconventional forces to blend in with non-combatant vehicles and introduces a great deal of clutter for U.S. forces attempting to distinguish between friendly and hostile actors. This was clearly the case during both main phases of OIF, when Fedayeen and then insurgents used civilian vehicles to avoid detection by U.S. forces. Civilian traffic can also provide cover, since the presence of genuine non-combatant vehicles discourages U.S. troops from firing upon combatant vehicles that they can identify. Situations where combatants intermingle with civilian traffic will thus be dangerous both for civilians and for U.S. forces attempting to identify disguised enemy combatants.

Third, enough civilian vehicle traffic has the potential to hinder U.S. vehicles attempting to maneuver in a city. As discussed in the previous chapter, the U.S. experience during Operation Uphold Democracy in Haiti in 1994 was an example where civilian traffic presented an impediment to U.S. military vehicles.[235] In a future situation where U.S. military vehicle again find it difficult to use roads, they may again need to use alternative forms of transportation with different vulnerabilities, such as helicopters. This could have implications for planning, logistics, and force protection.

Fourth, pedestrian traffic feeds into congregations, which results in crowds during various times of the day. Crowds are significant in urban operations in several ways. The interim U.S. Army field manual on counterinsurgency operations identifies four types of crowds: casual crowds, sighting crowds, agitated crowds, and mobs. Casual crowds are mere a gathering of people, while sighting crowds combine casual crowds and an event.

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[234] There is little information about the presence of civilian vehicles in Somalia during the battle in Mogadishu. While Aidid's forces also had technicals, much of the fighting appeared to involve Somali combatants and civilians on foot. Given Somalia's low rate of motorized vehicles per capita, this may not be unexpected.

[235] Written correspondence with Russell Glenn at the RAND Corporation on Operation Uphold Democracy. Pittsburgh, PA, October 4, 2004.

Agitated crowds are sighting crowds with emotion, and mobs are agitated crowds engaged in physical activity.[236] Casual and sighting crowds in Iraq and Panama provided inadvertent concealment for combatants (Iraq) and snipers (Panama). Casual crowds are also higher points of population density that again may produce a disproportionately large number of civilian casualties. For example, a marketplace blast in Baghdad in March 2003 produced many civilian casualties because people were congregated.[237] In Somalia, sighting crowds because agitated crowds and mobs that attacked U.S. forces and dragged the bodies of dead servicemen through the streets.

Figure 5-2. Crowd Around U.S. Serviceman During Operation Iraqi Freedom

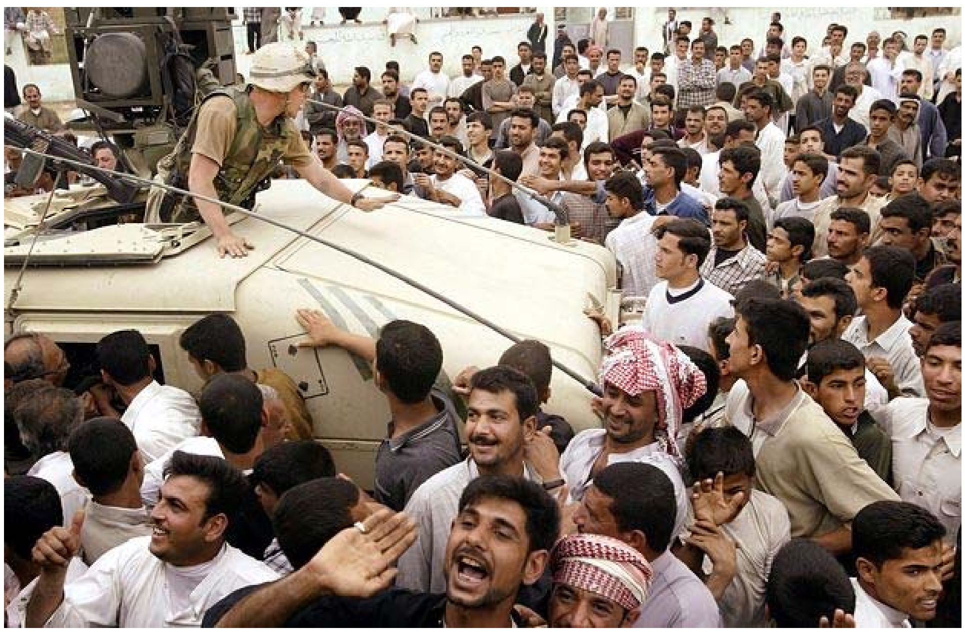

Photo: John Strycula

To what extent do commuting, congregating, and traffic exist during an urban operation? It is reasonable to assume that a great deal of travel and congregation may stop during intense urban operations or in anticipation of urban combat. On the other hand, there are reasons why they may happen even in the midst of combat. The case studies show that when U.S. forces achieve

[236] United States Army, Field Manual Interim 03-7.22, *Counterinsurgency Operations* (Washington, D.C.: United States Army, 2004), p. 6-11.

[237] John F. Burns, "Iraq Blames U.S. for Market Blast that Killed Civilians in Baghdad," *New York Times*, March 29, 2003, p. A1.

tactical surprise, they often encounter civilians who are traveling and commuting as they normally would. During OIF, Iraqi forces and Iraqi civilians were caught off-guard during the start of the ground war. Iraqis continued to travel in Baghdad and in other areas of the country even as U.S. ground forces had begun their offensive into Iraq. Civilians in Mogadishu were also traveling around the city, congregating at the market, and conducting daily activities when Task Force Ranger began their raid. Additionally, even when non-combatants are aware of urban fighting, some non-combatants may still attempt to travel for various reasons. For example, non-combatant deaths during operations in Panama included one family attempting to drive to the hospital.[238]

Lastly, even when background civilian behavior halts during periods of pitched battle, it is unlikely to go away completely and will resume as the intensity of fighting drops off. This is particularly true if an operation continues over an extended period of time. These background behaviors are also likely to be prominent during post-conflict operations after major combat has ended and non-combatants go back to some semblance of their previous lives. For example, most of the residents of Fallujah fled before a November 2004 USMC offensive against insurgents in that city. The lower density of civilians made the operation easier for the Marines and was also thought to have reduced civilian casualties. However, at the end of the operation, civilians were expected to return in large numbers as U.S. troops continued with lower-intensity counterinsurgency operations. The return of many military-aged men was expected to make it more difficult to identify insurgents, and the return of normal civilian traffic was expected to provide cover for suicide vehicles.[239]

Identifying background civilian behaviors that contribute to civilian casualties and that introduce operational difficulties for U.S. forces can also suggest ways to influence or manage these behaviors. U.S. troops in post-conflict Iraq are currently using curfews to curtail civilian travel during certain periods of the day in cities such as Mosul, where they were conducting counterinsurgency activities in late 2004.[240] Another area with room for further efforts may be in preparing an urban population for a U.S. offensive. During Operation Desert Storm and Operation Iraqi Freedom, U.S. forces conducted an extensive psychological operations (PSYOPS) campaign directed at Iraqi forces.

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[238] Buckley, p. 265.

[239] Patrick J. McDonnell, "Iraqi City Lies in Ruins," *Los Angeles Times*, November 15, 2004.

[240] Associated Press, "Insurgents Launch Attacks in Mosul," November 11, 2004.

This included leaflets and radio communication that included warnings not to take offensive postures and instructions on how to surrender.[241]

Currently, PSYOPS are sometimes targeted at civilian populations to influence support for U.S. objectives. For example, Figure 5-3 shows a U.S. flier during the start of OIF that warns people to stay in their homes and away from military personnel. It also shows a flier from 2005 warning civilians about unexploded ordnance:

Figure 5-3. U.S. Fliers Aimed at Civilians During OIF

Source: U.S. Central Command.

However, this could be expanded into a more extensive, preparatory campaign that would mirror the level of detailed instruction generally aimed at enemy soldiers. Before the start of an operation, PSYOPS targeted at Iraqi troops before the start of OIF included instructions on how to posture weapons, warnings against using weapons of mass destruction, and information to tune into certain radio stations for further information (Figure 5-4). A new twist on conventional PSYOPS against enemy forces may be PSYOPS explicitly directed at civilian populations to reduce civilian casualties, civilian exposure to danger, and confusion for U.S. forces on the ground. A parallel PSYOPS effort aimed at a civilian population could be part of a preparatory campaign to address the

241 U.S. Department of Defense, *Conduct of the Persian Gulf War,* p. 140.

issue of civilian casualties earlier. Even without giving away information on the timing and method of a U.S. urban ground offensive, it seems possible to convey significant amounts of information to a civilian population on approaching U.S. vehicles, curfews, or other travel restrictions that the population should follow once U.S. forces are sighted. Other instructions might include turning off music while driving (to reduce the chances of not hearing warnings), tuning into certain radio stations, or explanations of the rules of engagement. Such a campaign should be able to reduce confusion and civilian casualties at the beginning of future urban operations.

Figure 5-4. U.S. Fliers Aimed at Iraqi Troops at the Beginning of OIF, 2003

Source: U.S. Central Command.

Simple Reactions to Combat

The next topic to discuss in Chapter 5 is simple reactions to combat. Simple reactions to combat may be used in lieu of background behaviors to produce base non-combatant reactions in scenarios where urban combat is intense enough to bring a halt to most travel and congregation in the timeframe examined. When analysis covers a longer time period or an area large enough to have different localized events, these simple reactions to combat may be layered on top of background behaviors. Simple reactions to combat are: running away from combat, taking shelter, ignoring combat and continuing with present behavior, and running towards combat. Running away from combat and seeking and staying in shelter are obvious behaviors. However, non-combatants have also ignored combat or even advanced towards it. There are also instances where different groups of non-combatants exhibit three or four of these types of behaviors at once in close proximity to each other. Recreating the table of simple reactions to combat from Chapter 3:

Table 5-1. Simple Civilian Reactions to Combat

	Panama	**Somalia**	**Iraq Major combat**	**Iraq Post-conflict**
Run Away	Yes	Yes	Yes	Yes
Take Shelter	Yes	Yes	Yes	Yes
Ignore Combat	Vehicles	Uncertain	Vehicles Pedestrians?	Vehicles
Run Towards	No	Yes	No	No

The first simple and seemingly most rational reaction to combat is to run away from it. Fleeing from combat is a universal, defensive behavior that non-combatants showed across case studies. In Panama, civilians ran away from U.S. forces during lulls in the fighting. Even in Somalia, where civilians actively participated against U.S. troops, some people attempted to run away from U.S. forces instead. This is also a frequent behavior outside these case studies. Although it is a defensive action, running from combat does pose dangers to non-combatants. Fleeing civilians are vulnerable to crossfire between combatants and run the risk of being mistaken for enemy combatants.[242] They may also flee in the wrong direction and blunder into combat, or flee from one area where there is combat and find themselves in another battle scene. For U.S. forces, moving civilians on the battlefield make it more difficult to minimize non-combatant casualties and large numbers of fleeing civilians hinder attempts to engage enemy combatants.

The second behavior is seeking and staying inside shelter when there is fighting nearby. Related to fleeing, this is also a defensive and widely observed behavior among civilians caught up in urban warfare. Civilians may flee an area with fighting first and then seek shelter inside buildings once they are away from combat. Alternatively, they may run into buildings in an attempt to take cover regardless of how close they are to combat. Another way that non-combatants may exhibit this behavior is merely to go to ground: continuously staying inside a building as fighting approaches, while it occurs around them, and after it moves away.

There may be ways for U.S. forces to take advantage of the self-preservation instinct that drives running from combat and seeking shelter to manage civilian movement. Aside from attempts to manage normal civilian travel and congregation, there may be ways to purposely direct the flight reflex during the midst of urban combat to reduce non-combatant exposure. Again, U.S. forces have traditionally used PSYOPS tactics to influence enemy combatant morale and actions. During the 1991 Gulf War, 15,000 lb munitions and B-52 bombers were judged to have adversely affected Iraqi morale and to have encouraged surrender.[243] In Operation Enduring Freedom in Afghanistan in 2002, the USAF again dropped 15,000 lb conventional munitions known as "Daisy Cutters" on Taliban positions in 2003 and near Iraqi troops in 1991.[244] The USAF also attempted a "shock and awe" strategy of using spectacular explosions over Baghdad for similar reasons.[245]

The purpose of such operations was to impress upon enemy combatants the strength of the U.S. arsenal and the danger it posed to life and limb. It might be worthwhile for U.S. forces to explore ways that they could also signal their

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242 There is also little information available on how far civilians flee. It may be until they no longer sense combat; it may be to a specific location without regard for whether or not they can sense combat from there; or it may be to an area that their sources of information judge as safe.

243 Department of Defense, p. 140.

244 Nick Cook, "The Air Campaign – Trends and Developments," *Jane's Defence Weekly*, March 26, 2003.

245 Nick Cook, "The First Week of the Air War: Shock and Awe?" *Jane's Defence Weekly*, April 2, 2003.

lethality to civilians and encourage them to get out from the open and seek shelter. Such tactics could involve using flash grenades and other riot control devices that result in little damage but that encourage people to disperse or seek cover. One potential danger in using such tactics too often may be that people begin to ignore warning tactics or to underestimate the danger of real munitions. However, this is an area that could be further explored, particularly if the United States plans to conduct future operations in urban areas.

The third response to combat is a lack of reaction to what is happening. Non-combatants, particularly those in vehicles, at times ignored combat and continued about their normal daily activities. They appeared to do it because they were unaware of how close they were to combat, because they underestimated the danger they were in, or because some activities (such as seeking medical assistance) were urgent enough for people to take the risk. This is a behavior that occurred to varying degrees in the case studies. It was not as universal as defensive actions, such as running away from combat and seeking shelter. However, it did happen and U.S. forces are likely to encounter it again I the future. Ignoring the presence of combat poses risks for both non-combatants and U.S. forces. A related behavior to ignoring combat, ignoring U.S. forces as vehicle checkpoints, is also a behavior that can lead to numerous non-combatant casualties in Panama and especially in Iraq. Civilians appear to exhibit this behavior at times because they are not aware that a checkpoint exists, they underestimate the danger of approaching a checkpoint, or through other miscommunication and misunderstanding.

Again, better communication with civilians prior to the start of conflict or PSYOPS-like tactics to stoke defensive responses may reduce the number of civilians who fail to respond to the dangers of combat. It is doubtful that this behavior will ever completely disappear, since there will always be confusion, limited information, miscalculation, and miscommunication for civilians caught up in urban combat. However, there may be room to reduce the proportion of civilians exhibiting this behavior during combat and the effect might again both reduce civilian casualties and improve situational awareness for U.S. troops on the ground.

The last non-combatant behavior, running towards fighting, is the most unusual of the behaviors described in this chapter. Civilians in Panama and Iraq did not appear to exhibit this behavior on a large scale, although individuals who attacked U.S. troops or who ran to greet U.S. troops did.[246] In contrast, civilians in Somalia displayed it frequently. In Mogadishu, civilians ran towards the sound of fighting and gathered in crowds at the scene of gunfire. During U.S. troops' final retreat from the city, Somalis also gathered in crowds to watch them leave.[247] Running towards combat cannot be considered a defensive or a default behavior, unlike the ones mentioned up until this point. It is not a universal or easily explained non-combatant behavior. Nonetheless, this behavior is considered a simple reaction to combat because it is spontaneous, driven by a simple reflex, does not require planning, and does not involve complex interaction with combatants. It merits attention because it is a behavior that can lead to more aggressive civilian actions towards U.S. forces.

If the U.S. experience in Mogadishu is any indication of what can happen when large numbers of civilians are drawn to scenes of urban combat, it is definitely best to explore actions that would discourage this behavior. When it comes to ideas on dispersing crowds, non-lethal weapons naturally come to mind. Current types of non-lethal weapons in use or under development include nets, foams, and weapons aimed at nerve stimulation.[248] In addition to using non-lethal weapons to disperse crowds, the appearance of large and heavily armed U.S. forces might also be an effective way to discourage civilians from remaining at particular locations. (Task Force Ranger in Mogadishu was a small and light force, unlike the heavy armored units that appeared on the streets of Baghdad.) Just as PSYOPS might be directed at the civilian population specifically to reduce civilian casualties and unnecessary interaction with U.S. forces, shows of force might also be aimed at civilians for similar reasons.

Simple Behaviors and Agent-based Modeling

As discussed in the previous chapter, information on the size, composition, and density of a civilian population allows analysis on certain types of policy options. Introducing simple behaviors to this static population opens the possibility of using models to examine additional policy alternatives that could not be assessed before. Table 5-2 lists some specific options that could

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[246] Grayden Ridd, "Box One: Urban Operations With the 101st Airborne," *Jane's Intelligence Review*, July 1, 2003, p. 3.

[247] DeLong and Tuckey, pp. 95-6.

[248] Russell Glenn, *The City's Many Faces: Proceedings of the RAND Arroyo-MCWL-J8UWG Urban Operations Conference* (Santa Monica, CA: RAND Corporation, 2000): pp. 180-3.

be evaluated in models when certain types of non-combatant behavior are added:

Table 5-2. Civilian Population Characteristics and Potential Policy Options

Civilian Characteristic or Behavior Introduced to Model	Example Policy Options That May Now be Considered
Demographic information and population density	Force sizing Planning and resource management Weapons choice Targeting decisions Policies that affect density or total population
Commuting and congregation	Curfews Vehicle checkpoints and roadblocks Restrictions on congregation Operation timing (day versus night, etc.) Transportation requirements for U.S. troops
Simple reactions to combat	Effects of maneuver Rules of engagement Tactical surprise Information operations aimed at civilians Sensor technologies

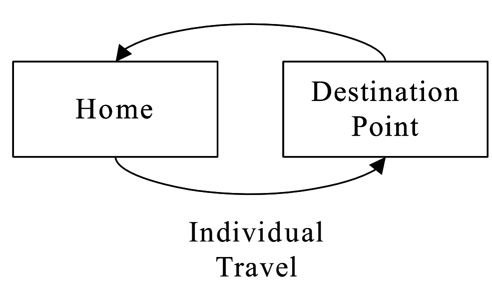
Introducing individual-level behavior for non-combatants in models requires a fairly high degree of model resolution. Although population density and heterogeneity in population distribution are attributes that could be incorporated into low-resolution models, much of what is discussed in this chapter pertains to models that can depict individual non-combatant agents. Vehicle density could be used in lower-resolution models to some extent, but traffic and individual reactions to combat require greater resolution. Because of this, this chapter begins to discuss non-combatant behavior more specifically within the context of ABM. The strengths of the ABM approach become evident during this discussion of simple non-combatant behavior. Trying to animate the numbers of non-combatant actors suggested in Chapter 4 may make it difficult to use approaches other than ABM. Non-combatant actors also need to be able to react to their specific local environment in order to emulate phenomena such as vehicle traffic and fleeing from fighting combatants. Also because various non-combatants may exhibit different types of reactions to combat at the same time, ABM is useful because it easily allows for this type of heterogeneity in behavioral rules.

Agents with simple behavior are enough in many agent-based models to produce complex, emergent behavior from the system as a whole. For example, the simple behavior of agents in a town moving around until their environment meets certain criteria for ethnic mix produces segregated neighborhoods. The relatively simple behavior of panicking people racing for an exit in crowd dynamic models produce casualties or not depending on the building's structural characteristics. Both in ABMs and in simpler cellular automata models, agents with routes and destinations produce traffic jams and congestion along simulated roads and at intersections. Introducing self-directed non-combatants into a military model should also produce emergent, system-wide behavior. Depending on any number of model characteristics, such emergent behavior could include patterns of non-combatant agent casualties or a relationship between red agent casualties and non-combatant movement.

There is a framework for modeling simple agent behavior that begins to emerge from just this discussion of background behaviors and simple reactions to combat. An interactive non-combatant population can be created by setting non-combatants to exhibit background behavior in the absence of combat, having simple reactions to combat come into play when fighting occurs around non-combatant agents, and instructing agents to revert to background behavior when agents no longer detect combat. This should result in varying, localized behavior that allows for the simulation of the "three block war" that often characterizes urban operations, even with only these simple behaviors. Disparate local events will also be especially true in scenarios where there is sporadic, low-level violence, such as in post-conflict Iraq.

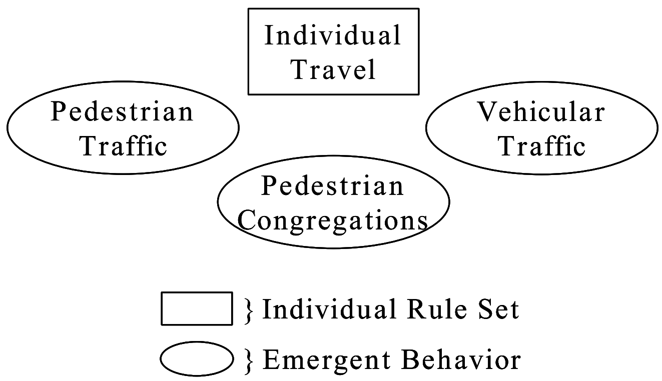
First, there are some points to be made about setting background behaviors for non-combatant agents. Although non-combatant behavior may differ substantially for some scenarios, a base model could consist of non-combatants carrying about background activities. People travel to and from a wide variety of locations where they meet, learn, worship, conduct business, or buy goods and services. Non-combatants in an urban ABM could be animated by having their default goals set for traveling and staying for various times at different locations. An individual agent travels according to the instructions it has about moving back and forth between its home and other destination points throughout the city.

Figure 5-5. Moving Between Destination Points



As agents travel, the *emergent* behaviors that arise from multiple agents making trips are *vehicle traffic*, *pedestrian traffic*, and *pedestrian congregation*. Traffic patterns arise as agents encounter other agents attempting to reach their destinations. Congregation happens when there are destinations that attract multiple agents, who may stay at that location for a certain period of time before traveling to another destination. Recreating Figure 5-1 but distinguishing between individual and emergent behavior yields:

Figure 5-6. Individual Rule Sets Versus Emergent Behavior for Background Non-combatant Behaviors



Here, individual agent rules about when and how to travel should create these other emergent behaviors. Figure 5-1 treated these behaviors as a pathway, where one leads to another. However, in the ABM framework, traffic and congregations are aggregate-level behavior that arises indirectly from individual behavioral rules.

Introducing heterogeneity in walking versus riding vehicles allows for agents to represent either vehicles or pedestrians. (The total number of vehicles might be a function of the total number of vehicles per population set for the scenario.) It would also be realistic to have are daily and geographic traffic patterns. It is reasonable to assume that traffic peaks during certain times of the day and falls off at night. Traffic will also depend on a number of other factors such as the day of the week, holidays, and patterns in economic activity. When thinking of traffic activity across a city, it would also make sense for locations to have varying degrees of “attraction” for people in vehicles making trips instead of assuming random activity throughout the city. This is more likely to produce variations in traffic and vehicle density that reflect real events.

It is not necessary to use a model with very complex rules to emulate traffic: even cellular automata models have given good approximations of realistic behavior. By setting attraction values for both buildings and open areas, it should be possible to reconstruct high population density points both inside and outside of buildings. Modeling traffic and congregation at the city block level may or may not be desired: depicting agents moving along roads certainly grants a higher fidelity to non-combatant movement. Alternatively, other types models may reflect traffic as population and vehicle densities that change over time for a given geographical unit. ABMs could also be used to generate these dynamic population densities, and the results could be fed into other types of models in lieu of adding non-combatant actors.

The next layer in such a proposed modeling framework is to add simple reactions to combat. Although activities around the simulated city can continue to be agents' primary objectives, agents should also have rules that direct them to deviate from their behavior (or not) in the event that they sense combat in their vicinity. This requires some awareness or information about the local environment for each agent. Such awareness is necessary for the highest definition traffic models, since individual vehicles will be required to slow down or speed up depending on the presence of other vehicle agents. Agents should either be heterogeneous in rules that dictate whether they flee, go to ground, or continue their activities. Alternatively, they may be assigned probabilities rather than rules for each of the possible actions. Although non-combatants had various motives for simple reactions to combat in the case studies, making these behaviors probability-based instead of situation-based would simplify rules and yet can expect to give rise to realistic emergent behavior. Such emergent behavior would include non-combatants running during firefights and finding non-combatants inside buildings as red or blue forces move through them. This is where the non-combatant actors proposed in this dissertation begin to break from the current state of the art in military modeling. Now, non-combatant actions are exogenously determined, with no feedback from the surrounding environment incorporated into behavior.

Running away from combat and seeking or remaining in shelter are two defensive non-combatant behaviors that are related. An entirely plausible set of rules could direct an agent who is out in the open to flee combat, seek shelter, and remain there. There may even be an error term that gives agents some chance of running in the wrong direction. These rules for fleeing combat could be coupled with directions for an agent to remain inside a building if it detects combat outside, but to flee and seek shelter again if fighting moves into the building. This should result in non-combatant agents running from building to building as they find themselves in the midst of combat. Here, possible rules are that agents remain inside buildings as long as there is fighting within their area of awareness. After that, one set of rules may be that they reestablish their normal routine after a randomly generated wait period. There is also leeway to emphasize one behavior over another, resulting in non-combatants who tend to stay inside shelter as much as possible, or non-combatants who tend to move even when combat is fairly distant. These types of variations across non-combatant populations are found in the real world. There is also plenty of room for experimenting with how likely it is for civilians in a simulation to ignore combat. The reaction to run towards combatants may be excluded or assigned a very low number of occurrences.

There is a great deal of heterogeneity and variation that can be introduced for non-combatant agents depicting these relatively simple behaviors. There is potential heterogeneity in behavioral rules, where agents may have different rules on how to react to combat. There is heterogeneity in parameters, such as the length of time an agent remains in shelter if it goes to ground or the probability that an agent will flee a given area if it detects combat. There may also be heterogeneity for a host of other factors, such as how accurately it can detect the presence of combatants. Another type of heterogeneity is differences in the demographic characteristics of agents. For example, men were much more likely to be traveling in Iraq after the immediate fall of the Hussein government because security concerns prevented many women from leaving their homes.

Behavioral heterogeneity among simulated civilian agents reflects the fog of war when not everyone response in the same manner. In a model, it may be useful in several ways. Variation in non-combatant behavior can test methods of distinguishing between friend and foe in high-resolution simulations. It should also be an advantage in training simulations since changing behavior can help keep circumstances challenging and results from becoming too predictable.

ABM also allows agents to communicate information with one another. Communication is an interesting dynamic that should almost certainly lead to non-linearities and other interesting phenomena. Communication between agents in a model can also allow researchers to pose questions about PSYOPS, civil affairs policies, and the role of information. It can be represented as simply as having non-combatant agents observe the behavior of other non-combatant agents. Introducing elements of social behavior could lead to non-combatants running away from the vicinity of combat even though they have not directly observed combat themselves, but have observed other non-combatants fleeing an area. Rules may instruct an agent to flee with some probability if they detect combat in a given area and to flee with some *additional* probability if they observe other non-combatants fleeing. An alternative is to represent communication between agents through an extended sensory range for non-combatant agents. Information passing between agents would effectively increase the geographical area that non-combatant agents perceive. Agents could also have imperfect, incorrect, or incomplete information about combat in their extended ranges, reflecting the uncertain nature of communication during the fog of war.

Yet another way to capture communication between agents is to use networks. Here, agents are members of networks and learn from other agents in their network. Networks and communicating agents are often used to model technology diffusion and social learning and they could also be used to model non-combatant communication. Networks may reflect neighborhood, kinship, clan, or ethnic ties between civilians. It is important to note that such networks need not necessarily be contained within geographical boundaries: in real life civilians may be in communication with others in different areas of the city or in different areas of the country. Communication along networks can be used to represent information passing between civilians through phone, Internet, radio, TV, and other media that do not require physical proximity. Thus information between non-combatants could jump areas, with some non-combatants farther from the fighting having more information than some who are closer. In the context of the simple behaviors described in this chapter, networking could, for example, prompt non-combatants in another area of the city to seek shelter. Networking also has relevance when modeling complex behavior that requires non-combatant agents to have more information.

Example: Hypothetical FCS Model

The example model in the previous chapter used leadership strikes during OIF to show how information about population density can be used to reduce civilian deaths. Using population density data is appropriate when considering urban operations that mainly affect stationary civilians. For this reason, the OIF leadership strike example did not need to go beyond density data. However, in many cases, adding civilian movement and simple reactions to combat introduce enough new information to alter the policy recommendations that come from models with a static non-combatant population. The example section of this chapter looks at how this is expected to be the case when evaluating the Future Combat Systems (FCS) program. It will look at the policy implications of a RAND FCS study that used population density to answer questions about civilian casualties. It will then explore how dynamic civilians in a simulation change recommendations and allow analysts to consider a wider scope of policy alternatives. The purpose of this exercise is to demonstrate how introducing more complex civilian behavior into a model now makes it possible to evaluate an expanded range of policy options.

The FCS program is central to the U.S. Army's efforts to transform itself from a Cold War era force into one that is lighter and more mobile. When fully developed, the FCS program will be a suite of 18 systems. These systems are scheduled to include eight new manned ground vehicles, four unmanned air vehicles, unmanned ground vehicles, sensors, and missiles.[249] Connected by an advanced information network, these components are expected to produce a system of systems that should be as lethal, as survivable, more readily deployable, and sustainable with a smaller logistics footprint than the current heavy armor vehicles they replace.[250] FCS vehicles will be "medium" weight (20 tons) and deployable by air, instead of "heavy" like the M1 Abrams (70 tons).[251] The fundamental idea behind the FCS is that substituting superior information for mass will allow the Army to realize all these goals simultaneously.[252] Current plans call for the Army to equip 15 brigade-sized forces with the FCS over the next 20 years.[253] According to some observers, the Army has accepted cancellation of two other major weapons systems – the Comanche helicopter and the Crusader artillery system – in order to preserve funding for the FCS.[254]

Many FCS technologies are still under development and the actual design of the FCS may not be finalized until 2008 at the earliest.[255] In the absence of a physical prototype, there is no choice but to use modeling and simulation to test notional FCS performance. As part of the 2000 Army Science Board's look at "Technical and Tactical Opportunities for Revolutionary

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[249] United States General Accountability Office, *Future Combat Systems Challenges and Prospects for Success* (Washington, DC: Government Printing Office, 2005), March 16, 2005, GAO-05-428T, pp. 3-4.

[250] GAO, *Future Combat Systems Challenges and Prospects for Success*, pp. 4, 6; and United State General Accountability Office, *Issues Facing the Army's Future Combat Systems Program* (Washington, DC: Government Printing Office, 2003), August 13, 2003, GAO-03-1010R, p. 8.

[251] John Matsumura, Randall Steeb, Tom Herbert, John Gordon, Carl Rhodes, Russell Glenn, Michael Barbero, Fred Gellert, Phyllis Kantar, Gail Halverson, Robert Cochran, Paul Steinberg, *Exploring Advanced Technologies for the Future Combat Systems Program* (Santa Monica, CA: RAND Corporation, 2002), pp. 1-2. Henceforth referred to as Matsumura, et. al.

[252] GAO, *Future Combat Systems Challenges and Prospects for Success*, p. 5.

[253] Tim Weiner, "An Army Program to Build a High-Tech Force Hits Cost Snags," *New York Times*, March 28, 2005.

[254] Weiner.

[255] GAO, *Future Combat Systems Challenges and Prospects for Success*, p. 17.

Advances in Rapidly Deployable Joint Ground Forces in the 2015-2020 Era," the RAND Corporation's Arroyo Center for Army Research used high-resolution modeling to evaluate the value of different potential FCS technologies in a SSC. The SSC was set in Kosovo and involved the FCS against Serbian armor. Serbian armor capabilities were upgraded compared with current capabilities in order to account for improved capabilities in the future.[256] In real operations against Serb forces in Kosovo, NATO relied on airstrikes and did not use ground forces. In its modeling scenarios, RAND examined the results from relying on airstrikes and other long-range indirect fires, and the results from adding FCS capabilities on the ground.

To estimate non-combatant casualties from FCS long-range fires, researchers used different population densities to represent urban versus sparsely populated areas. The estimates assumed that there was a uniform population density and a given probability of injury depending on the distance from an aerial strike. They also assumed that more munitions would be fired when a target was harder, when the payload was smaller, and when the CEP of the munition was greater. Thus, the most civilian casualties came from using the smallest munition with the largest CEP against the hardest targets.[257] The policy implication of this type of casualty estimate is that certain munitions, depending on the CEP and the payload, should not be employed in the FCS. The results from such a model imply that to reduce civilian casualties, decision makers should use the most accurate munitions available. Also under the targeting assumptions outlined in the report, using a smaller munition may increase civilian casualties because more munitions must be fired at a target to ensure a certain probability of damaging it. However, this implied relationship between weapons choice and civilian casualties might not necessarily hold because it ignores civilian movement. Civilian travel and movement in response to combat could be a far greater driver of non-combatant injuries than the choice of FCS munitions. Had a model with detailed non-combatant behavior been available to the researchers who conducted the study, it would have been possible to ask this question.

There are similarities between the RAND civilian casualty estimates and the example model discussed in Chapter 4. Although many of the assumptions are slightly different, at their core, both models envision warheads going off over a stationary and uniformly distributed non-combatant population. This assumption was more or less accurate for the OIF leadership strike example.

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[256] Matsumura, et. al., pp. xiii, 4.

[257] Matsumura, et. al., pp. 28-31, 65-75.

However, it was much less realistic for the Kosovo scenario. The terrain examined in the RAND modeling scenario was mostly roads, fields, and villages instead of urban residential areas. Population movement would have been the primary driver for civilian exposure. The study results point out the range of civilian casualties that could result from different population densities and are consistent with such a view.

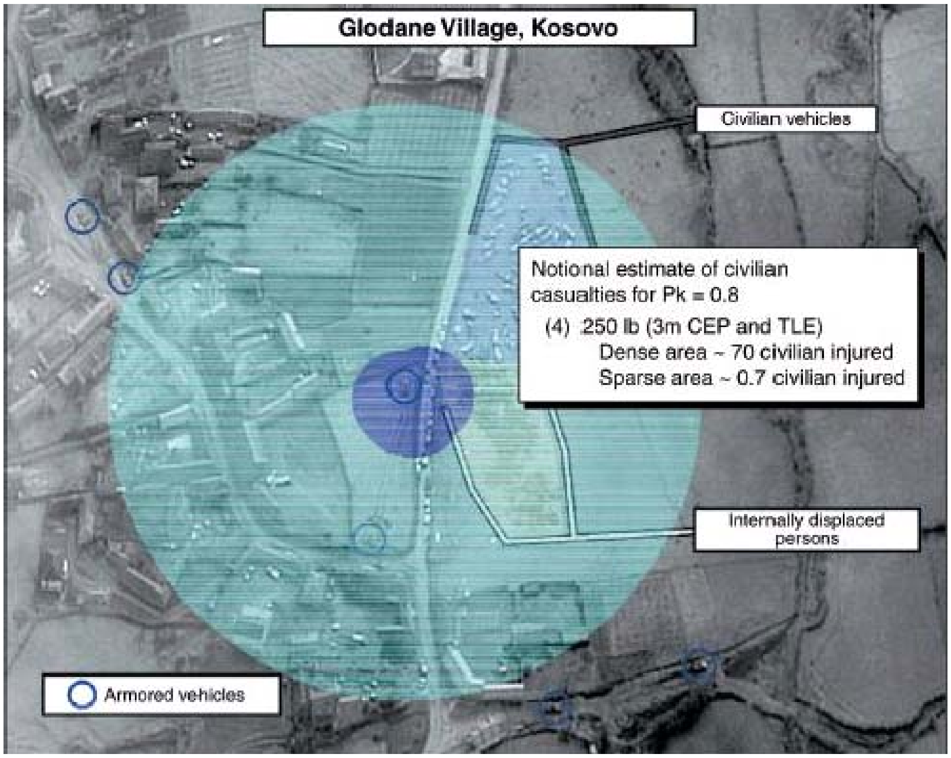
In some cases, local population density around targets was greater than average in real life: Serbian forces compelled civilians to act as human shields during Operation Allied Force in 2000, increasing the population density around certain targets.[258] In other cases, using the average population density overestimates civilian casualties. The scenario assumed that ethnic Albanian civilians would stand around uniformly distributed in open areas where there are Serbian tanks, explosions, and other combat activity. Human shields were not present around all Serbian targets, and for these, using uniform population density would overestimate civilian casualties. This is because it would be natural for non-combatants to flee or to avoid combat areas. The modeling scenario also did not take differences in terrain into account when estimating civilian casualties. For examples, civilians are more likely to be concentrated on roads because of civilian traffic than in rural areas just meters from a main road.

Figure 5-6 is taken from the RAND FCS study and depicts the use of four 250-lb JDAMs with a 3-meter target location error (TLE) and 3-meter CEP against armored targets in Kosovo. The blue inner circles depict the effective area against the targets, while the outer green circles show the possible injury range for non-combatants in the area[259]:

[258] Matsumura, et. al., pp. 65-9.

[259] Matsumura, et. al., pp. 29-31.

Figure 5-7. Illustration of Noncombatant Effects of Dropping Four 250-Pound JDAM With 3-Meter TLE



Source: RAND MR-1332-A.

Adding the simple behaviors discussed earlier in this chapter would go a long way towards introducing civilian behavior that is appropriate for this scenario. (This is actually suggested from Figure 5-6, which points out an upper and lower bound for civilian casualties based on different population density assumptions. Using different density assumptions is the simplest way to depict a dynamic population that may move around relative to target locations.) Civilians in this model should have rules that direct them to run or drive away from areas where they observe combat. This creates very basic non-combatants whose motion can still influence the policy suggestions that come out of the model. Instead of policy options being limited to FCS weapons choice, potential policy levers now include ways to influence civilian movement. It is also now possible to examine the potential impact that rules of engagement, different FCS sensor technologies, and other options can have on civilian casualties and other MOE.

Adding other simple population characteristics also paves the way to ask further policy questions. For example, Figure 5-6 shows civilian vehicles on the road near Serbian armor. Although the RAND study did not model civilian vehicles, this would clearly be a concern in real life. Having civilian vehicular traffic in a model would offer a more realistic test of how often proposed FCS technologies are able to distinguish and engage armored targets among additional sensory clutter. Examples of technologies that could be used by the FCS include 1) advances in remote assets such as synthetic aperture radar (SAR) and foliage penetration radar (FOPEN) equipped satellites; 2) organic tactical sensors such as low-flying fixed-wing UAVs, hovering UAVs, and air-deliverable acoustic sensors (ADAS); and 3) armed and unarmed robotic reconnaissance ground vehicles.[260] It is a distinct possibility that adding civilian vehicles that substantially outnumber Serb armored vehicles into the modeling scenario could alter the assessment of these different technologies. For example, it may show that a certain candidate technology is less suitable than it formerly appeared because it now consistently mistakes civilian vehicles for legitimate targets. Another technology may not be as stellar as an alternative in killing Serb armor, but may balance this with fewer civilian casualties. Or, yet another technology may show a previously hidden talent for discerning civilian vehicles.

In addition to simple movement and reactions to combat, there are two other non-combatant behaviors that would be appropriate when recreating the Kosovo scenario from Operation Allied Force.[261] The first behavior is a directional refugee flow. During the fighting between Serbs and ethnic Albanians in Kosovo, approximately 300,000 ethnic Albanians fled to neighboring Macedonia.[262] The second behavior is the use of involuntary human shields by Serb forces. Involuntary human shields are discussed in further in the next chapter and are listed as a complex non-combatant behavior in this dissertation. However, it is also possible to model this form of human shield behavior by initially placing some civilians close to certain targets and having them not react to combat.

Table 5-3 illustrates how even simple civilian behaviors can allow researchers to ask additional policy questions. It lists one of the behaviors dealt with in this chapter and proposes a policy question that researchers for the FCS program might have been able to investigate if a model with interactive non-combatants had been available. Again, the baseline analysis is FCS long-range fires over a stationary and uniformly distributed population. In that scenario,

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[260] Matsumura, et. al., pp. 15-7, 22-3, 41.

[261] Recreating the all-air power campaign from the actual Operation Allied Force versus recreating a counterfactual with an FCS ground force may have different implications for the magnitude or prevalence of these behaviors.

[262] "Still Nervous in Macedonia," *Economist*, Vol. 363, June 10, 1999.

the primary policy questions that can be asked in the analysis revolve around weapons choice and usage. Table 5-3 also goes a step further and lists ways that Serb forces did or might have used these civilian behaviors to counteract NATO actions. Asking this question automatically generates ways to make enemy combatants in a model more life-like and challenging to confront.

Table 5-3. Simple Non-combatant Behaviors and FCS Program Analysis

Civilian Behavior Introduced to Model	Additional Policy Questions	Potential Serb Use of Civilian Behavior
Vehicle traffic	How does proposed FCS technology perform when vehicle clutter is added? Can civilian traffic be controlled in a way to maximize FCS effectiveness?	Use civilian traffic for cover and concealment.
Fleeing from combat/ seeking shelter	How can civilian exposure to combat operations be reduced?	Force civilians from their homes to raise number of civilian casualties from NATO actions.
Ignoring combat (approximation for human shields)	What tactics help counteract the Serb use of human shields? What technologies better target enemy combatants in close proximity to civilians?	Force civilians to act as human shields.
Directional refugee/IDP flow	How should NATO plan for humanitarian assistance? What techniques can control or manage mass civilian movement?	Create refugee flows. Close borders to increase exposure for civilians caught inside the country.

One this that Table 5-3 makes clear even without completed model runs is that the presence of non-combatants could greatly complicate FCS operations in even modestly built-up areas. There is substantial potential for Serb mischief with ethnic Albanian civilians that would reduce FCS systems' ability to distinguish between combatants and non-combatants. It raises questions about whether the systems' projected informational superiority would be great enough to overcome these types of low-tech tactics. There is also the possibility that refugee movement and civilian traffic could hinder maneuver, another important anticipated element of the FCS program.

6. Complex Non-combatant Behaviors

Chapter Six deals with complex non-combatant behaviors. It identifies and discusses the implications of some of the complex behaviors found in the case studies: looting, involuntary human shields, voluntary human shields, attacking U.S. forces, and swarming. This chapter expands on the simple behaviors introduced in the previous chapter and introduces pathways for combining complex and simple behavior. The next section of Chapter Six deals with modeling these complex behaviors in an agent-based framework. It discusses potential behavior rules, adaptive, and emergent non-combatant behavior. The last section offers an example of how complex behaviors might be used in a model to further expand the range of policy questions that can be examined.

Adding Complex Behavior

Up until this point, this dissertation has discussed population density, background movement, and simple reactions to combat. This has laid the supporting layers for the set of complex behaviors that will be discussed in the following section. There are a number of reasons why incorporating complex non-combatant behavior into models, simulations, training, and analyses is a worthwhile endeavor. Complex behaviors are some of the most important because they include the most hostile and most extreme behaviors that civilian can exhibit towards U.S. forces. Large-scale looting or swarming can easily overwhelm the ability of U.S. troops to control a population or even to operate at all. Even when behaviors are not widespread, hostile actions such as attacking U.S. forces still have important ramifications for how U.S. forces carry out their activities. Being able to recreate this set of behaviors in models or other planning and training tools improves the ability of U.S. forces and decision makers to understand and prepare for difficult civilian behavior.

Another reason that complex behaviors are important is that explicitly considering them can change and improve overall planning and conceptualization of urban operations. The exercise of attempting to deal with the uncertainty in complex behaviors and the expanded range of situational implications forces broader thinking about uncertainty, risk, and robust solutions. Complex behaviors are more uncertain and more situation-specific than the background and simple behaviors discussed so far. Thus, adding the final layer of complex non-combatant behavior greatly expands the uncertainty, the complexity, and the range of potential events that can come from an urban population far beyond what arises from considering only population density and simple behaviors. This greater range of events happens because there is much more uncertainty in whether or not civilians will exhibit complex behaviors such as looting, human shields, and attacking U.S. troops than for simple or background behaviors.

One complex behavior, looting, illustrates this point that extending the range of potential civilian behaviors that the defense community plans for may be beneficial. U.S. forces appeared to be unprepared to deal with the widespread looting in Panama that took place in the wake of Noriega's fall.[263] This was a significant civilian response that greatly shaped the environment that U.S. troops faced as they attempted to shift to post-conflict operations. The real problem, however, was the fact that this experience did not leave the United States any more ready to deal with looting in Iraq after the fall of Saddam Hussein's government. Instead, policy makers and troops on the ground again seemed to be caught unprepared to intervene successfully in the looting and lawlessness that marked the beginning of the U.S. presence in post-conflict Iraq. Hindsight is always 20/20, but if the possibility of looting civilians had been considered more explicitly in analysis, simulation, or training in the twelve years between Operation Just Cause and Operation Iraqi Freedom, looting in Iraq might have been less of a surprise.[264]

The complex behaviors discussed in this chapter are not exhaustive and are better thought of as a start to systematic research into non-combatant behavior. The behaviors identified generally tilt towards those that are more aggressive or disruptive for U.S. forces. It is certainly not the case that all U.S. military activities will only be met with negative reactions. It would not be accurate to expect this. However, there is a low cost to being pleasantly surprised by cooperative or helpful behavior and a high cost to being caught off-guard by hostile or impeding behavior. Preparations and planning for a military engagement tend to focus less on the ways that an adversary may fall short of performing as an effective fighting force and more on the ways that they might.

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[263] Fishel, p. 60-1.

[264] Interestingly enough, at the time, there was also criticism that U.S. military planners had not sufficiently prepared for looting in Panama. Fishel, for one, disputed the claim that there had been a conscious decision to dedicate manpower to other higher-priority missions and questioned how planners who were normally intelligent could fail to miss this possibility. If looting in Panama in 1989 and looting in Iraq in 2003 both came as a surprise to U.S. forces, it is clearly time to be explicit about this possibility when planning future urban operations.

Similarly, research resources would be better spent on understanding and preparing for aggressive or disruptive civilian behavior.

This chapter also does not offer a compendium of civilians "types" that correspond to each of the behaviors. This was deliberately avoided because transitions between different types of behaviors can be fluid. Civilian populations can generally be characterized as friendly, hostile, or neutral, because of the behavior that predominates. However, individual behavior can vary considerably throughout a population and over time. For example, some of the same civilians who greeted U.S. troops in Iraq could very well have later become looters or insurgents. The discussion of non-combatant behaviors in this dissertation provides only a brief overview of the way civilians may transition between different attitudes and acts towards U.S. forces. Yet the topic deserves considerable further attention. If there are common patterns across many cases on how civilians shift from one behavior to another, it would be very valuable information for understanding and managing populations in future operations. Solid theory for how large numbers of individuals begin to "swing" towards one behavior or another, combined with computational experimentation with emergent behavior, could greatly improve current insight into non-combatant populations.

This chapter also attempts to avoid suggesting that culture is the primary cause of any of these behaviors. Leaning too heavily on culture often blinds researchers to other situational factors that may have contributed to certain actions. It encourages narrower thinking about a population's motives, adaptability, powers of observation, and ability to learn. The danger to tagging the behaviors discussed in this dissertation as atavistic to certain cultures or areas of the world is that it may encourage outdated beliefs about a society for years after a conflict. This would be the equivalent of "fighting the last war" when it comes to considering possible non-combatant behavior in that country during future conflicts. A good example of this mentality is how U.S. military planners assumed that OIF would produce a refugee crisis because the 1991 Gulf War had produced one. Although there is no evidence that they believed cultural reasons were behind this, the point is that planners may have automatically assumed that it would happen in 2003 because it had in 1991 even though conditions were very different. Greater understanding improves analysis, training, planning, and other preparation for future conflicts. Anchoring a certain expected behavior to a certain population does not improve understanding and should not be done.

Complex Behaviors

The following table recreates Table 3-4 in the case study section and summarizes the complex civilian behaviors that this chapter discusses:

Table 6-1. Complex Civilian Reactions to Combat

	Panama	Somalia	Iraq Major combat	Iraq Post-conflict
Looting	Yes	No	Yes	No
Involuntary Human Shields	No	No	Yes	Yes
Voluntary Human Shields	No	Yes	No	No
Attacking U.S. Forces	Yes (Rare)	Yes (Frequent)	Yes (Rare)	Yes
Swarming	No	Yes	No	No

As previously stated, this is not mean to be an exhaustive list of all complex behaviors that civilians can display towards U.S. forces. The table focuses on physical movement and actions that can prompt direct engagement by U.S. troops. It does attempt to identify the ones that have had the most serious implications for U.S. urban operations in recent years, even though some of these behaviors may be fairly uncommon. The ultimate goal is to explore ways to manage or prevent some of these civilian responses in the future.

Beginning with the first complex behavior in the table, widespread looting was evident in Panama and Iraq. Looting in areas such as Panama City, Colon, Baghdad, and Basra started spontaneously as soon as it became apparent that the government was no longer in power. Looting in Panama appeared to begin in shopping districts while looting in Iraq began at government buildings. In each of these locations, looting gained momentum as time went on: more and more people joined in on the looting, the scope of the looting broadened to other targets, and looters became more brazen and more violent. Looting typically died down in a few days as looters began to run out of goods to take. On the whole, Panamanian and Iraqi looters appeared to be undeterred by the presence of U.S. troops when they began breaking into buildings. U.S. troops had some local success in restraining looting in Panama, but could not stop the full extent. U.S. forces were also dealing with manpower constraints and other mission objectives at the same time.

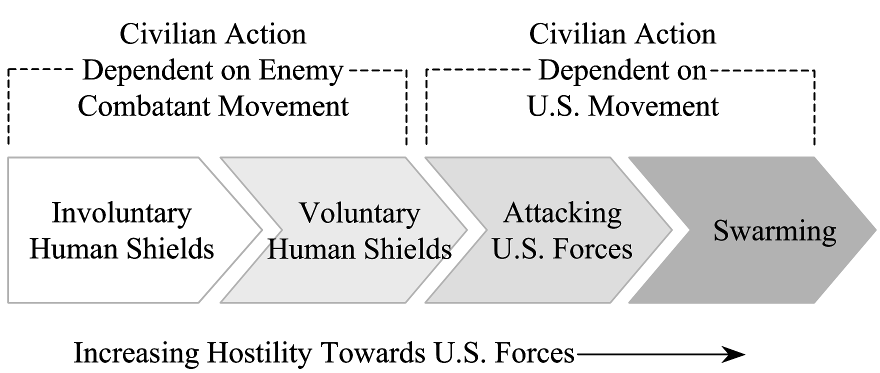
To what extent should the United States be concerned about looting as future a non-combatant behavior? On one hand, looting did not take place until after the United States had accomplished its objective of overthrowing the Noriega and the Hussein governments. Nor does it occur in every urban operation. Nonetheless, widespread and prolonged looting is disruptive enough that U.S. forces should be concerned about the possibility that they will encounter it again in the future. Additionally, it is usually consistent with U.S. interests to leave a country in a reasonably stable and functional condition when it withdraws forces. The damage that looting during OIF did to Iraq's already fragile infrastructure required the United States to pour additional resources into physical repairs and into reestablishing law and order. It prolonged the process towards establishing a stable country, which in turn prolonged the period of time that U.S. forces had to stay in Iraq.

Further research is needed on this phenomenon to better understand the dynamics of widespread looting and how U.S. forces can stop, prevent, or mitigate it. The U.S. experience in Panama and Iraq suggest some theories for when it happens. In both cases, the United States targeted internal security forces that were responsible for both law enforcement and for keeping the government in power. Looting happened after U.S. forces successfully undermined these security forces. Thus, the collapse of internal security forces in Panama and Iraq led to the fall of the Noriega and Hussein governments. However, the collapse of these security forces also may have encouraged people to believe that they could loot with immunity. Both governments were also unpopular and appeared to have low legitimacy among its citizens, which may have emboldened civil disobedience in the wake of their demise. Again, however, not much can be said only looking at only two instances and a more in-depth look is necessary before one can arrive at any policy recommendations.

In addition to investigating the causes and potential warning signs for why civilian populations engage in widespread looting, it would be helpful to identify methods to deal with looting and to give estimates on the types and sizes of forces potentially required. Modeling and simulation are potential tools to use for this purpose. Live humans used in training exercises to stand in for civilians cannot capture all aspects of a civilian population that is looting. This is because widespread, spontaneous looting across a large urban area might potentially involve thousands of people. It also involves sustained activity that escalates over days and would be difficult to recreate in an exercise. Instead, this appears to be a problem where modeling and simulation could offer a great deal. U.S. forces in future urban operations are likely to be lean, given this country's continued efforts to substitute capital and technology for labor in its armed forces. Further analysis on looting might even suggest that these anticipated force levels would be insufficient to control large urban populations once looting and the breakdown of law and order has started. Yet even this would be valuable information, since efforts could then be directed to preventing the start of looting. Such efforts might involve better identifying the preconditions for widespread looting, or more a more involved PSYOPS campaign before hostilities aimed at the civilian population precisely on this issue.

Looting may largely be thought of as a standalone behavior. Except where U.S. forces are attempting to control looting, it generally does not involve significant civilian interaction with either enemy combatants or U.S. forces. (In Iraq, looters ignored U.S. forces and looted whether they were present or not.) However, the other behaviors discussed in this chapter are civilian responses to combatant actions. Non-combatants acting as involuntary or voluntary human shields engage in behavior that is closely tied to the activities of enemy combatants. Civilian attempts to attack U.S. forces, or to swarm, require actions closely tied to the movement of U.S. troops. The following figure depicts these relationships and arranges civilian behaviors according to how hostile they are towards U.S. forces:

Figure 6-1. Civilian Interactions with Combatants



Non-combatants acting as involuntary human shields is the least hostile of the behaviors depicted in Figure 6-1. It may even be thought of as a defensive measure on the part of non-combatants because they are cooperating with enemy combatants in order to avoid harm. With involuntary human shields, civilian behavior is (involuntarily) coordinated with enemy combatant behavior. There are a few different types of involuntary human shields. At a passive level is a conventional army's decision to store munitions dumps, weapon, and vehicles near protected civilian structures such as schools or religious buildings. This was what Iraqi conventional forces did during OIF. Deliberately operating in densely populated residential areas should also be considered employing a form of involuntary human shields. Pulling individual civilians into harm's way during combat is a much more active form of using involuntary human shields. Enemy combatants can force non-combatants to travel with them, to stay between them and U.S. forces, or to move forward first in the presence of U.S. troops. All were tactics shown by the Fedayeen during major combat operations in Iraq.

The study of involuntary human shields is actually a study of unconventional enemy combatant tactics. Whether or not there are involuntary human shields, to what extent they are used, and what shielding behaviors are common all depend on the enemy. In most cases it will be difficult to know beforehand whether or not a certain opponent will use involuntary human shields as actively as the Fedayeen did in OIF. However, preparing for the possibility is still important. The use of involuntary human shields clearly increases non-combatant casualties by bringing them deliberately into the line of fire. Involuntary human shields also endanger U.S. forces, because they are not able to fully engage combatants who are using non-combatants for cover.

The next behavior is civilians acting as voluntary human shields. Here, civilians actively coordinate their movement with combatants', placing themselves between combatants and U.S. forces. This civilian behavior is primarily dependent on enemy combatant movement and behavior. It also only occurs in the presence of U.S. forces, since human shields are pointless if there are no U.S. troops in the vicinity. Similarly to involuntary human shields, voluntary human shields increase the danger to both civilians and to U.S. forces. At the same time, voluntary human shields appear to be uncommon compared with background behavior or even with involuntary human shields.

It might be possible to see both involuntary and voluntary human shields in the same conflict. This was not true in the case studies: overall, there were voluntary human shields in Somali and involuntary ones in Iraq. Somali civilians backed Aidid's rule in Mogadishu and sided with militiamen against U.S. forces. Fedayeen had no interest in protecting Iraqi civilians and chose to exploit them to their advantage instead. Looking at this, one might suggest that a positive relationship between civilians and enemy combatants results in no human shields or voluntary human shields; while a forced or discordant relationship between them could lead to involuntary human shields. However, it is easy to imagine a situation where both would occur. One example could be a conflict involving opposing factions or ethnic groups, where enemy combatants have positive relations with one group and antagonistic ones against another. U.S. forces attempting to intervene in such a case could very well see both types of human shield behavior simultaneously.

Another thing to note is that non-combatants acting as either voluntary or involuntary human shields may *appear* to be exhibiting some of the simple reactions to combat discussed in the previous chapter. For example, civilians who are being compelled to stay in a certain location may appear to be ignoring combat around them. Others who are being forced to accompany combatants or to precede them to discourage U.S. fire may appear to be running or traveling in the direction of combat. Non-combatants acting as voluntary human shields may also appear to be ignoring combat or running towards combat. In real life, there tends to be considerable confusion for U.S. troops confronting numerous civilians exhibiting different behaviors at the same time. It may be easy to mistaken one type of behavior for another under such circumstances.

Attacking blue forces is the next level up in aggressive civilian behavior. Here, the line between hostile civilians and enemy combatants disappears. For the purposes of this dissertation, people are still considered to be civilians rather than enemy combatants if they attack U.S. forces in a way that tends to be spontaneous, uncoordinated, and not part of a planned or organized group. Unlike background travel, simple reactions to combat, or the role of non-combatants as human shields, there is quite a deal of variation within this category of behavior. Variations in behaviors previously described in this dissertation tend to be a matter of degree: non-combatants in a given situation are more or less likely to flee from combat, or more or less likely continue driving around a city. On the other hand, there are a number of separate behaviors that fall under the umbrella of attacking U.S. troops. Actions in this category include individuals firing at U.S. personnel, groups of civilians attacking vehicles, or crowds becoming hostile toward U.S. troops who are present. There are times when attacking U.S. forces clearly turns a non-combatant into a combatant, despite factors such as age or gender. Some actions such as suicide bombing or shooting U.S. forces would clearly cross the line and make such actors combatants. However, it is far less clear whether a group of unarmed civilians surrounding a U.S. military vehicle and hurling stones should be regarded as combatants. Another case where the line between combatant and non-combatant is blurry is when enemy combatants compel a non-combatant to attack.

Swarming is the ultimate hostile behavior that civilians can show towards U.S. forces. This dissertation uses a definition of swarming used in military case studies: a swarm occurs when multiple attackers converge on a target from multiple directions. Action ebbs and flows as the swarm converges and disperses.[265] It does consist of individual civilians attacking U.S. forces. However, what distinguishes it from this category is the presence of coordination and the magnitude and persistence of the attacks. It is typically done by combatants on the battlefield and extremely rarely by civilians. When civilians do swarm, it represents such an escalation in hostility that it can be distinguished from other types of attacks on U.S. forces. For example, there was a qualitative difference in the Somali civilians swarmed against U.S. forces in Mogadishu and confrontations between hostile crowds and U.S. forces in the Balkans, Iraq, and other conflicts.

There is little doubt that civilian swarming poses substantial hazards to both civilians and to U.S. military personnel. Large numbers of armed or unarmed civilians converging on U.S. forces will clearly lead to casualties on both sides. An enemy combatant taking the opportunity to use a civilian swarm as cover or as a diversion would also be able to inflict greater damage on U.S. forces while potentially taking fewer casualties themselves. Although there are many examples of swarming in military engagements throughout history, civilians' swarming upon military forces is quite rare. Although there is little data available on civilian swarms outside of Operation Continue Hope, this one case does suggest some possible causes of civilian swarming. It is plausible that civilians may be most likely to swarm when a civilian population is exceedingly hostile and the military force in question is small, light, isolated, and retreating.

As non-combatant behavior in urban operations becomes more complex, the interplay between different types of civilian behavior also becomes more complex. The most hostile behaviors, attacking U.S. troops and swarming, are likely to be the climax in a sequence of other non-combatant behaviors. For example, civilians may first rush towards the sound of combat, congregate, voluntarily act as human shields, attack U.S. forces, and ultimately begin to swarm. Non-combatant behavior need not culminate with this level of hostility towards U.S. personnel, but this example shows how behavior might progress down such a path. The following figure attempts to capture some of the dynamics of operations in Somalia:

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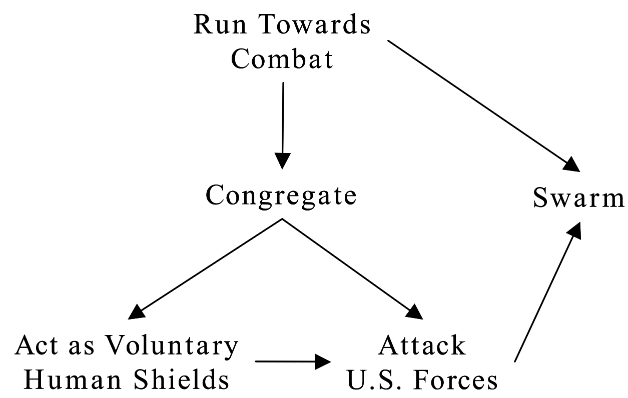
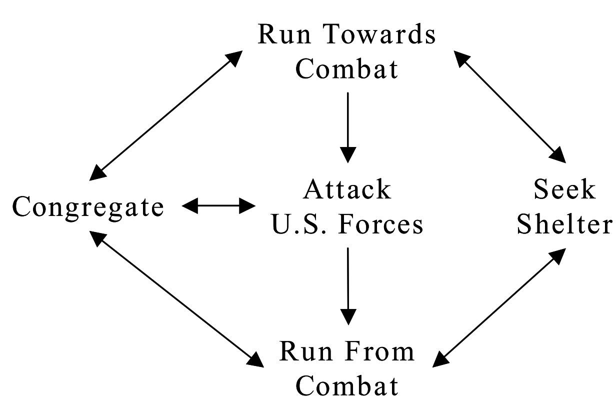
[265] Edwards, *Swarming and the Future of Warfare*, p. 2.

Figure 6-2. Sample Pathway of Hostile Civilian Behaviors



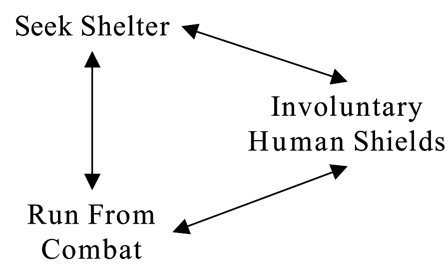
Additionally, civilians might move between different types of behaviors without a clear progression of actions. Even when they become hostile towards U.S. forces, they may be sufficiently deterred from escalating events beyond a certain point. Civilians might instead cycle through various hostile and non-hostile behavior:

Figure 6-3. Sample Transition Between Hostile and Non-hostile Civilian Behaviors



Non-combatants might also cycle between purely non-hostile actions. Neutral or fundamentally friendly non-combatants could potentially switch back and forth between running from combat, seeking shelter, and occasionally acting as involuntary human shields. (Such a dynamic appeared to be present in the early stages of OIF.) This type of transition back and forth between different types of defensive acts would be reasonable since non-hostile behavior, unlike hostile behavior, cannot really be said to escalate:

Figure 6-4. Sample Transition Between Non-hostile Civilian Behaviors



The way that civilians transition between behaviors will also be affected by the interaction between combatants and non-combatants, and it is clear that enemy combatants could use this as a deliberate strategy. For example, enemy combatants alter the dynamic between civilians and U.S. troops when they disguise themselves as civilians. Although a given civilian population may be generally neutral or even friendly at times towards U.S. forces, a few experiences with disguised combatants will result in U.S. forces treating civilians as potential combatants. This could then lead to more inadvertent civilian deaths and injuries, which could then lead to tensions between U.S. troops and non-combatants. Enemy combatants may also make use of the more complex civilian behaviors – human shields, attacks on U.S. forces, and swarming – to provide concealment and cover, reduce situational awareness, immobilize, or gain intelligence. They can also use civilian reactions to win strategic victories: insurgent violence against Iraqi civilians undermined the U.S. strategic goal of political and economic stability in post-conflict Iraq.

There is the opportunity for enemy combatant actions to combine synergistically with complex civilian behavior in ways that increase the danger or difficulty that U.S. troops face. Much of it will depend on the enemy combatants themselves, but civilian behavior can also have a dramatic impact when taken together with enemy combatant behavior. The urban environment will tend to magnify these effects due to the high number of non-combatants and the complexity of urban warfare. For these reasons, it is important to study civilian behavior both on its own and as a component of an opponent's tactics. The ability to manipulate civilian interactions with U.S. forces is part of an asymmetric strategy that unconventional forces can use against the United States in urban areas. Non-combatants may also become combatants, then act as non-combatants again during the course of a conflict. This also adds another layer of complexity to the problem and is intimately tied to the nature, goals, and tactics of a particular enemy combatant.

Including complex civilian behaviors and the transitions between behaviors in military models and simulations would add another tool to the case studies, lessons learned, and other methods that are currently being used to improve understanding in this area. For one, modeling and simulation can provide a larger laboratory for experimenting with non-combatant behavior than is offered by live exercises or actual operations. Additionally, models and simulations with complex civilian reactions can illustrate what is already known about civilian behavior and can serve as training tools for those preparing for future urban operations.

Complex Behaviors and Agent-based Modeling

Just as adding simple behaviors to a static population expanded the range of policy options that a model could consider, introducing complex behaviors on top of these two previous layers provides the means to assess additional policy alternatives. Table 6-2 adds to Table 5-2 by adding complex behaviors. It also includes communication, learning, and adaptation – these can be added when a model has only simple behavior, or both simple and complex behavior. With the introduction of complex behaviors into models and simulations, it is then possible to assess more sophisticated policies than before. For example, a model with commuting and congregation allows polices such as curfews and vehicle checkpoints. A model that adds civilian human shields and attacks on U.S. forces allows researchers to ask questions about more advanced crowd control tactics.

Table 6-2. Civilian Population Characteristics and Potential Policy Options, Continued

Civilian Characteristic or Behavior Introduced to Model	Example Policy Options That May Now be Considered
Demographic information and population density	Force sizing Planning and resource management Weapons choice Targeting decisions Policies that affect density or total population
Commuting and congregation	Curfews Vehicle checkpoints and roadblocks Restrictions on congregation Operation timing (day versus night, etc.) Transportation requirements for U.S. troops
Simple reactions to combat	Effects of maneuver Rules of engagement Tactical surprise Information operations aimed at civilians Sensor technologies
Widespread looting	Strategies to prevent looting Methods to control looters
Human shields, attacking U.S. forces, and swarming	Rules of engagement Crowd control tactics Non-lethal weapons Methods to discourage human shields Countermeasures to human shields
Communication, learning, and adaptation	PSYOPS and information operations directed at civilians

In dealing with the complex behaviors discussed in this chapter, ABM has a number of advantages over the alternatives discussed in Chapter 2. Again, ABM allows for the localized effects that can simulate the "three block war" where the environment that U.S. forces face is very different over a span of a few city blocks. Two of the complex behaviors, looting and swarming, lend themselves to being modeled as emergent behaviors. Additionally, civilian behavior that can progress towards higher and higher levels of hostility can be obtained by using adaptive agents. What follows in this section are some suggestions for potential rules to recreate complex non-combatant behaviors within an ABM. This is by no means the only way that these behaviors could be simulated. Instead, it is meant to be a starting point for encouraging experimentation with agent rules that could introduce these behaviors into urban combat models.

In the literature on agent-based modeling of numerous social dynamics, agent rules are not necessarily judged on how complex or detailed they happen to be. Rather, they are judged on whether they realistically approximate what is know about individual behavior and whether they generate realistic emergent behavior. Rules that direct agent actions in stock markets, civil disobedience, global climate change, smallpox transmission, and technology diffusion tend to be specified by various authors without undue emphasis on recreating the exact parameters that reflect reality. Researchers instead formulate behavioral rules that are consistent with general information about individual behavior and then use the resulting emergent behavior as a test for whether the rules are acceptable or not. Similarly, successful non-combatant agent rules are those that not only reflect plausible individual reactions but those that also recreate recognizable patterns of emergent civilian behavior in past urban operations. The rules proposed in this section need to be tested in simulations to see what emergent patterns arise before they can be considered adequate. It is hoped that those with the resources to experiment more extensively with non-combatant agent-based rules will be able to confirm or improve upon the rules offered here.

Starting with the first complex behavior in Chapter 6, looting is a phenomena that appears to be a good match with ABM. There should be some probability in a simulation that a few non-combatants will begin to loot if blue forces overwhelm centralized red forces. Looting should also be more likely to occur in certain locations in the city, regardless of whether or not these areas saw combat. Looting should spread from a few geographical points in a downtown area to a much wider area, peak within a day or two, and diminish as looters run out of goods to take. The presence of looters should encourage other non-combatants to become looters. Looters in the immediate vicinity of clashes between blue forces and looters should become less likely to loot. However, looters may have different behavioral rules for interacting with blue agents who are *not* shooting looters, such as ignoring them, avoiding them, or diminishing looting in their immediate presence. As the prevalence of looting increases, looters should be more likely to ignore blue forces who are not using lethal force. This could be because the presence of other looters is psychologically reinforcing or because individual looters judge that they are less likely to be singled out by blue forces if there are more looters. (It is also possible to have some type of injury rate for non-combatants who participate in the looting or who are present.) These types of non-linear rules would conceivably allow looting to escalate or to diminish partly due to the nature and size of the blue force response.

The next behavior to discuss is non-combatant agents acting as involuntary human shields. Non-combatants acting as human shields should stay near red forces, follow them around, or come between red and blue forces. Involuntary human shields will only be present when red forces decide to coerce nearby non-combatant agents to act as cover. Unlike other non-combatant behaviors that arise from internal civilian agent predispositions, involuntary human shields are driven by the behavioral rules of red force agents. There will have to be coordination between red agent behavioral rules and non-combatant agent rules, plus reactions in the face of blue agents. Figure 6-4 showed how non-combatants might cycle through various types of defensive behavior and an individual non-combatant agent's decision to run from combat, seek shelter, or act as an involuntary human shield could be based on what action has the highest defensive value at that moment given the immediate environment. In general, involuntary human shields are more common than voluntary human shields. Most scenarios are likely to have significantly more of the former type of behavior than the latter. As mentioned earlier, it may not always be evident that non-combatants are acting as involuntary human shields as opposed to exhibiting other behaviors. In real life, individual civilian intentions are often opaque to blue force combatants, who can only observe behavior and not internal beliefs or motivations.

For voluntary human shields, non-combatant agents should run towards combat and place themselves between blue forces and red forces, providing cover for red agents. Civilians may follow red forces around and act as human shields when blue forces come into view. Alternatively, they can act as human shields when both red and blue forces are present, but not follow red forces from one location to another. Adaptive rules may have civilians more likely to act as voluntary human shields if they see others acting in a similar fashion, but less likely to do so if they observe casualties among voluntary human shields and the enemy combatants who use them. Yet another form of voluntary shielding behavior may be for civilians to offer their homes as shelter or bases of operations for combatants. One way to seed the start of voluntary human shields may be to give non-combatant agents a random probability of becoming one as their internal hostility level towards the blue team increases. In some cases this threshold will never be reached. In other cases, it may be possible to have this behavior start spontaneously and spread to other civilians. One thing to note is that modeling voluntary human shields brings very unpredictable behavior into a simulation because this non-combatant behavior will depend on red agent behavioral rules plus the presence of blue forces. Red agent behavioral rules need to be able to accommodate voluntary as well as involuntary human shields.

Devising behavioral rules for simulating civilians who attack blue forces is a much more complicated task because there are numerous individual and group acts that fall under this category. In a very simple ABM it may be possible to simulate non-combatants attacks on blue forces as "hits" that blue agents take on their "health" or other barometer that determines whether or not a blue agent is functional or a casualty. If it is possible to simplify it to this level, it may be sufficient to have individuals or groups of non-combatants who attack isolated blue agents, individual blue vehicles, or small forces of blue agents. On the other hand, models with very high resolution and fine detail in the actions that blue forces have open to them may need additional information about individual civilian acts against blue forces. (These would include very high fidelity training models.) Also, civilians may exhibit isolated acts of aggression against blue forces (attack and run), or acts may escalate as the actions of some attacking civilians encourage others to follow suit.

A possible rule set to simulate escalating behavior may define whether or not an agent attacks as a function of: hostility (H), risk aversion (R), perceived danger from blue forces (D), and the presence of other civilian agents attacking blue agents (O). An agent should be more likely to attack when H and O are high; and less likely when R and D are high, whatever the particular functional form used in a simulation. These values should also be dynamic over time. It may also make sense to have values of H and R unique to individual agents, while making the agent function that determines values for D and O standard across agents. (One may also choose to express R as a function of the other variables instead.) This type of rule set should allow for random attacks from individual agents, for crowds to turn ugly, and for attacks to stop when civilians are sufficiently deterred by blue forces. Setting the initial parameters of H and R also controls the general disposition of a non-combatant population. There were attacks on U.S. forces even from the relatively friendly Panamanians, supporting the idea that it is realistic to randomly seed even a benign population with a few agents who are either very hostile or not risk adverse. Hostility could be set exogenously to reflect pre-existing feelings towards blue forces, or set as a function of civilian casualties or some other function to make civilian reactions truly interactive. This would certainly be an interesting feature to add in simulations that cover SOSO, peacekeeping, and post-conflict "Phase IV" operations that span long periods of time.

Swarming, another hostile act, is an *emergent* behavior that arises from the dynamics of individual attacks on blue forces. Civilian agents converge on blue forces along multiple lines of attack and may disperse and attack again. Yet swarming can still be considered emergent because individual attacks are not centrally directed but are the result of decentralized action. Although agents may communicate with each other, swarming arises as individual agents pursue internal goals. When enough civilian agents are persistent in attacking blue agents, they may cross the threshold from individual attacks into swarming behavior.

In reality, there seem to be several conditions that need to be met before civilian swarming will occur, such as a large number of hostile civilians, a small number of blue agents, or retreating blue agents. (Each condition is likely to be necessary to create a civilian swarm, but also likely to be insufficient to induce swarming by itself.) Using a rule framework like the one specified above should be consistent with the creation of civilian swarms only when such extreme conditions are met. Incorporating two simple behaviors into this framework – running away from combat and running towards combat – may even be sufficient to produce opportunistic swarms that can disperse and reconstitute themselves, depending on the circumstances. There is room for considerable experimentation with swarming behavior in an urban simulation. One should again be reminded that a civilian swarm is an unusual phenomenon and will only very rarely be encountered in real life.[266] However, adding swarming behavior to models offers an extreme environment for simulated testing of weapons systems and tactics.

In addition to swarming, some of the other behaviors depicted in the potential behavioral pathways are themselves emergent behaviors. Revisiting the sample pathway of hostile civilian behaviors from Figure 6-2, *Congregate* and *Swarm* should be treated as emergent behaviors. An individual agent cannot really congregate or swarm. Instead, it is the actions of multiple agents that constitute a congregation or a swarm:

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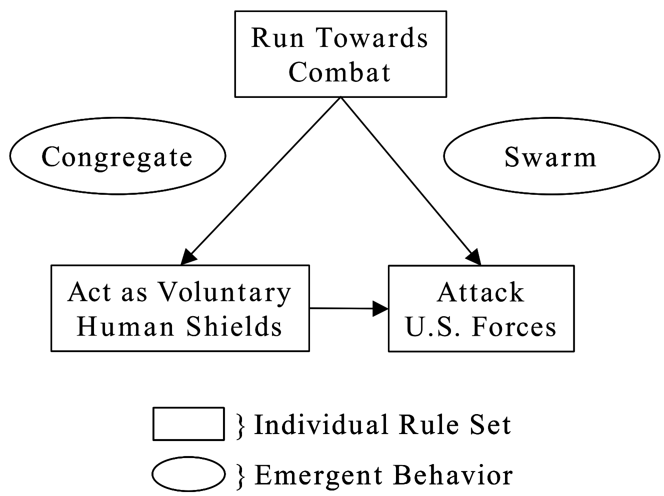
[266] See Edwards, *Swarming and the Future of Warfare*, for a history of swarming on the battlefield. Edwards identifies Somali militia as the swarm participants in Operation Continue Hope on pp. 262-8. However, Somali civilians also participated in attacks on U.S. forces and also converged on U.S. locations according to Bowden's version of events. Hence, it appears correct to say that civilians also swarmed in that case.

Figure 6-5. Individual Rule Sets Versus Emergent Behavior for Agents in Sample Pathway of Hostile Civilian Behaviors



It may help to think of each behavior inside a box as directed by a separate rule set that instructs an agent whether or not to express that behavior. Another important point to make is that moving between the boxes with individual rule sets and following a behavioral pathway constitutes adaptive agent behavior. When a civilian agent goes from acting as a voluntary human shield to attacking U.S. forces, it shows adaptive behavior because it follows different rules based on feedback from its environment and the actions of other agents around it. In order to allow for this adaptive behavior, agents need to have instructions on when to transition from one rule set to another. Looking at Figure 6-5, an agent may have *Run Towards Combat* as its default rule set when combat takes place (presumably agents would carry out background activities otherwise). However, agents may then be instructed to evaluate whether it will follow the rule set for acting as voluntary human shields based on whether civilian hostility exceeds a certain threshold, perceived danger is below another, and red forces are standing out in the open. The behaviors that arise from the actions of multiple agents is emergent behavior that has not been explicitly programmed into rule sets. The sample behavioral pathways in Figures 6-2, 6-3, and 6-4 can thus be thought of as combinations of rule sets, instructions for whether to transition from one rule set to another, and the emergent behavior that arises from individual agent actions.

There are numerous behavioral pathways that give a plausible sequence of non-combatant behavior and plausible emergent behavior. These pathways may be directional, culminating in a particular behavior; or cycling back and forth between different complex or simple behaviors. In addition to the possible ways that any individual behavioral pathway could be specified, there are many different ways that agents may be instructed to chose whether or not it proceeds down a particular pathway. Agents may be asked to evaluate internal parameters of factors within their immediate environment to decide whether or not to follow a rule set. An alternative way to deal with behavioral pathways is to treat it as a Markov matrix. Instead of evaluating a set of decision rules, agents may remain in a particular behavior, transition to one behavior, or to another based on globally set probabilities. Although modeling a behavioral pathway as a Markov matrix means that agent behavior is not adaptive, it may be appropriate when non-combatant preferences are so strong and so insensitive to the immediate environment that they may be treated as exogenous. The Markov matrix method is also likely to be sufficient for many purposes, since adaptive behavior is not necessary to produce emergent behavior, and since sometimes simpler is better.

It is also reasonable that many different pathways would exist in the same non-combatant population at the same time. Some civilians may be inclined to be hostile, some may be averse to encountering blue forces, and some may tend to underestimate or overestimate the physical danger they face in the vicinity of combat. How many agents belong to what pathway is one set of parameter values that introduces heterogeneity among non-combatant agents. Heterogeneity among individual parameters such as risk aversion and hostility will also mean that agents move down the same behavioral pathway at varying rates. Non-combatants are not homogeneous in real life and the mix of characteristics for a simulated non-combatant population should depend on the type of scenario that a simulation is meant to represent. Because U.S. troops will encounter different mixes of non-combatants in future operations, recreating the specific friendly/hostile mix from Panama, Somalia, or Iraq is of limited value. Instead, experimenting with different mixes of parameters and pathways is more useful than overusing any one particular non-combatant behavioral pathway.

Depending on how detailed one wishes to be about non-combatant behavior, there are other behavioral aspects that can be modeled using ABM. Some of these finer behavioral points may or may not make a difference compared with how basic rules and pathways are specified. However, they are possible and merit mention. Learning is one aspect that can be readily incorporated into agents in an ABM. Agents have internal variables that can be set to reflect past experience and can thus be said to learn. For example, perhaps a non-combatant agent initially attaches a high level of danger to the presence of any blue agent. Assume that its perception of danger (D) is a function of how many non-combatants it observed being injured (I) in the presence of a blue agent during the previous *n* number of time periods and the present period *t*:

$$D_t = f\,(I_t, I_{t-1}, I_{t-2}, \ldots, I_{t-n})$$

This agent should then perceive blue forces as less dangerous over time if it sees few or no non-combatants injured when blue forces are present; and blue forces as more dangerous if it sees non-combatants consistently or recently injured.

Communication is another behavior that can be captured within an ABM. There are several types of communication possible. Updating global variables that all non-combatant agents can observe would capture widespread, perfect, and near-instantaneous communication. News that a central government has collapsed might be most appropriately modeled this way, with implications for behavior such as looting. Communication between agents might also be locality or network based. If based on locality, agents may have an expanded range of observation because they hear from neighboring agents around them. Agents may flee or seek shelter even though combat is further away than they can observe because they are able to communicate about events over longer distances. Introducing an error term into information transmissions or making communication possible only a fraction of the time would make communication more realistic by making information incomplete and sometimes incorrect.

Another way that communication is often modeled in ABMs is through networks: agents learn from and receive information through others in their network. For non-combatant agents, networks can reflect ethnic or kinship ties. Such networks can be geographically spread out and represent information skipping physical distance. Non-combatant agents need not be restricted to communicating strictly with other non-combatant agents. They could communicate with red or blue forces as well, both receiving information from and giving intelligence to combatant agents. Passing information to either red or blue side would effectively extend the range of situational awareness for the force in question.

The possible universe of different rule and parameter combinations is a vast one, even before introducing variables for red and blue agents. With the great complexity that is possible for non-combatant behavior, simulated events become even more unexpected, non-linear, and interesting when adaptive blue and red agents within a model begin to interact with adaptive non-combatant agents. In particular, there is considerable room for exploring the red strategies that emerge when the red force is an unconventional or paramilitary force operating in a sea of non-combatants. How do red forces employ the presence of non-combatants? How do non-combatants advertently or inadvertently act as force multipliers for red agents? And most importantly, what can blue forces do about it, acting either directing against red forces or indirectly in their interactions with civilians?

The point of being able to create complexity in simulated civilian populations is to offer a laboratory for experimenting with a crucial aspect of the urban environment that cannot be recreated on a large scale in real life. It is hoped that having such a tool will enhance strategies for managing urban populations, offer insight into countering enemy opponent tactics in an urban environment, improve training, exploring tactics, and encourage more robust planning. Further discussion along these points continues in Chapter 7. Table 6-3 below summarizes the agent rules that might be used for the different complex behaviors. The table also includes the policy significance of some of these behaviors, as a reminder that the ultimate point is to improve actual decisions in future urban operations.

Table 6-3. Complex Behaviors, Agent Rules, and Policy Significance

Non-combatant Behavior	Summary of Proposed Agent Rules	Policy Significance of Modeling Behavior
Looting	• A few looters emerge spontaneously • Looters are encouraged by other looters • Looting is discouraged by blue forces shooting looters • Looting continues until there is nothing to loot.	• Identify potential tactics for controlling or avoiding widespread looting in future operations • Force requirements to prevent widespread looting in future conflicts
Involuntary Human Shields	• Civilians follow red agents, stay near them, or come between red and blue agents • Actions driven by red agent behavioral rules	• Evaluate tactics to minimize non-combatant casualties • Explore ways to discourage behavior
Voluntary Human Shields	• Civilians come between red and blue forces • Agents are more likely to act as voluntary human shields when others do the same • Agents are less likely to do so when they witness civilian casualties • Agents may follow red agents around	• Explore ways to counteract and discourage behavior
Attacking U.S. Forces	• Civilians attack when hostility is high and other civilians are also attacking blue forces • Civilians attack when risk aversion and perceived danger from blue forces are low	• Test non-lethal weapons and peacekeeping tactics in simulations
Swarming	• Emergent behavior that happens when large numbers of individual civilians carry out sustained attacks on blue forces along multiple axes of attack	• Modeling swarming civilians provides an extreme simulated environment for platforms and tactics.

Example: Hypothetical Looting Model

The purpose of the example in Chapter 6 is to illustrate the ways that a model with complex civilian behavior might be used to improve policy decisions. This example examines the type of widespread looting behavior that was present during Operations Just Cause and Iraqi Freedom. In these two cases, looting began almost immediately after the central government had fallen and escalated out of control before subsiding three or four days later. Modeling should help explore the dynamics of citywide looting – how looting spreads, how looters are deterred at the local level, and how individual actions lead to emergent behavior at the city scale. Gaining insight into these dynamics will in turn give a number of policy recommendations for future operations where a breakdown of law and order is expected to bring wide scale looting. Such recommendations include manpower requirements, suggested tactics, and city-level deployment strategies for a force attempting to prevent or control looting. The following thought exercise is an example of how a hypothetical looting model would be able to guide decision-making in each of these areas.

This example considers a hypothetical ABM looting model. As discussed in Chapter 2, aggregate models for non-combatant behavior will not be able to incorporate research on the behavior and decision-making process of individual looters. Nor are aggregate models able to demonstrate the effects of local dynamics or geographical concentrations of buildings and goods that would be attractive for looters. There are also significant problems with other approaches that *are* able to incorporate individual behavior and localized events: live exercises, constructive modeling, and HITL modeling. As mentioned earlier in this chapter, live exercises involving large numbers of participants pretending to be looters are fraught with substantial practical difficulties. Additionally, such exercises are as susceptible to modeler bias as any computer simulation: the instructions given to participants on how to act as looters will reflect the bias and preferences of the exercise designer as surely as any coded instructions given to virtual looters.

Lastly, constructive and human-in-the-loop modeling of large numbers of looters is also impractical. Although both allow for individual actions and different local dynamics, it would be impossible for either method to handle the large number of looters needed to approximate citywide looting. As a policy problem, looting does not necessarily scale – the policy implications of 100 people looting may be very different in nature from the policy implications of 10,000 people looting. In other words, the latter cannot necessarily be dealt with as if it were 100 of the former. For this reason, it is better to consider the effects of numerous looters. After introducing these criteria for handling localized events and large numbers of individual actors, ABM is the last method left standing. Its other advantages – its ability to handle many different types of agents and numerous model runs over different scenarios – further bolster its case.

A perfect agent-based model of looting behavior would have complete and accurate information on the different participants and potential participants, true behavioral models for each type of participant, and perfect means for translating individual actions into precise patterns of group behavior. A perfect model would also consider every single factor that could affect individual or aggregate looting behavior, including psychological attributes, perception, communication, and inter-group political grievances. Needless to say, it is impossible to ever build this perfect model. First of all, unlike the movement of physical objects or the outcome of chemical reactions, predicting human behavior is an endeavor fraught with uncertainty. Second, looting is a form of crowd and mob behavior, and the dynamics of crowds and mobs are not always well understood.

There is much that *is* known about crowd and mob behavior. For instance, more recent empirical work contradicts earlier notions that crowds are homogeneous entities. Additionally, crowds are not made up of isolated individuals but of "companion clusters"; participants have many differing motives and seldom act in unison; participants do not necessarily believe they are anonymous; and crowds may be thought of as a process with a beginning, middle, and end.[267] However, there are still considerable gaps in the understanding of crowd behavior. For example, there are no consistent predictors for the intensity of rioting mobs. The reasons for why crowds gather are also not always well understood. Additionally, the study of crowd behavior has almost exclusively focused on Western events and little is known about how crowds in other cultures might differ. More research is also needed to determine what psychological, social, cultural, and situational factors contribute to violent crowd behavior.[268] Considerable more work needs to be done on these types of fundamentally basic questions before a theoretically perfect simulation of any looting crowd is even conceivable.

While the perfect looting simulation cannot even be attempted at this point, models that are still less than perfect can be useful sinces shortcoming in a model can be assessed and compensated for when applying it for policy purposes. Constructing an ABM has the potential to provide 1) a means for theoretical inquiry into what is still unknown, and 2) a means for exploring the implications of what *is* currently known. On the first point, there have already been calls to use ABM to explore the type of crowd behavior that could arise from different combinations of participants and ranges of behavior.[269] While

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[267] John M. Kenny, Donald N. Farrer, Sid Heal, Steve Ijames, Clark McPhail, Dick Odenthal, Jim Taylor, and Peter Waddington, *Crowd Behavior, Crowd Control, and the Effects of Non-Lethal Weapons* (Pennsylvania State University Applied Research Laboratory, Human Effects Advisory Panel, January 2001), p. 1. Known henceforth as Kenny, et. al.

[268] Kenny, et. al., pp. 1-3.

[269] Grieger, *An Overview of Crowd Control Theory and Considerations for the Employment of Non-Lethal Weapons*, pp. 12-3.

this use for ABM might seem the most relevant for theory-building research rather than for policy analysis, both types of applications are actually useful for improving policy decisions. This is because exploratory use of either type of model can raise basic assumptions and help explore a fuller range of scenarios than will appear when relying exclusively on past experiences. When there are still unanswered questions about the basic nature of a phenomenon (such as crowd behavior), using a model for theoretical inquiry at least provides hypotheses or a framework for approaching a problem.[270] In other words, even when ABM results are insufficient by themselves to offer firm policy recommendations, they help to explore relationships and to generate ideas about policy options.

On the second point, using a model that focuses on capturing what is known can raise questions about risk and uncertainty – two components of problems that are often overlooked but that are vital to crafting policy options in urban operations. This is because unexpected results from a plausible model, even when the results in question are unlikely, forces decision makers to confront the possibility of such outcomes.[271] Being able to generate a range of scenarios is particularly useful in attempting to come up with robust solutions over a landscape of possible conditions or situations.[272] Possible examples of these uses will be discussed in further detail below.

Turning next to proposing agent rules for a hypothetical model, this exercise assumes that looters are rational. Compared with some types of crowd behavior, looting may be thought of as opportunistic and relatively rational. Other types of crowds may have goals that change over time, such as volatile crowds. In contrast, the goal of most looters is fixed and does not change as behavior or conditions around them change: it is to carry off material possessions.[273] Because looting is considered to be less emotionally driven than some other types of crowd behavior, the actions of individual looters will be more calculating. For example, some experts find that looting mobs last longer than other types of crowds because of greed. At the same time, looting mobs

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[270] Steve Bankes, "Explorabory Modeling for Policy Analysis," *Operations Research*, Vol. 41, No. 3 (May-June 1993), p. 440.

[271] Bankes, p. 440.

[272] Robert J. Lempert, Steven Popper, and Steven C. Bankes, *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis* (Santa Monica, CA: RAND Corporation, 2003), pp. 42-4.

[273] Grieger, *An Overview of Crowd Control Theory and Considerations for the Employment of Non-Lethal Weapons*, p. 2.

tend to be easier to break up because there is little emotional content.[274] Looters may vary in the intensity of their desire to acquire loot; the degree to which they are deterred by authorities; the extent to which they are emboldened by the presence of others; and other factors. These variations do not change the underlying assumption that looting behavior is fundamentally rational at its core. Varying parameter values across individuals easily accommodates these variations.

Next, this exercise uses the suggested looter behavioral rules discussed in the previous portion of this chapter. These suggested rules for agent behavior came out of the case studies.[275] Civilian agents are assigned a heterogeneous propensity to loot. They are more likely to loot given the presence of other looters and a concentration of items to loot. This should make looting a phenomenon that feeds on itself, but also one that burns out over time. Agents also have a heterogeneous initial deterrence factor that makes them less likely to loot in the presence of blue agent troops. This exercise also assumes that agents are less deterred by the presence of a blue agent if there are more looters in the same area (a lower concentration of blue agents per x number of looters). This would reflect the idea that people are emboldened when they have a lower probability of being individually picked out by blue agents. Additionally, agents can be adaptive: the deterrence factor can change over time as agents learn about blue behavior. Agents could be more readily deterred by the presence of blue agents if they saw them taking action in previous time periods, but less likely to be deterred by them if blue agents failed to react in the past. Introducing communication between agents and letting information change behavior is another way to make them adaptive. If all these agent rules listed above are realistic, the macrobehavior that results from them should be consistent with the looting that was observed in Operations Just Cause and Iraqi Freedom.

The first set of model runs should represent cases where there is no intervention. That is, what happens after the local police force collapses and blue forces are not present to deal with looters? This sets a baseline scenario that can be compared to other model runs with different types and levels of blue agent intervention. It is also useful for theoretical inquiry because it helps shape a basic understanding of how looting gains momentum and identifies the key drivers that affect momentum. Given the limited number of alternative methods

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[274] Grieger, *An Overview of Crowd Control Theory and Considerations for the Employment of Non-Lethal Weapons*, pp. 3-4.

[275] A complete examination of the type of rules that belong in looting models would involve collecting as much data from actual cases of citywide looting as possible. Such data would include video footage, eyewitness interviews, and written accounts of events.

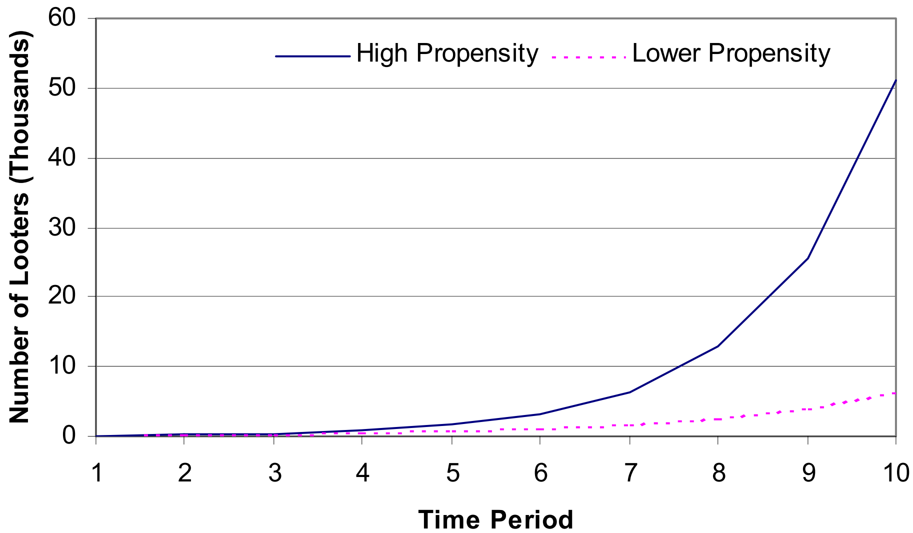
available for testing hypotheses on looting dynamics, even the baseline scenario may be valuable for basic research on the phenomenon. A baseline ABM can allow researchers to illustrate what is currently known about widespread looting and to conduct hypothetical cases by varying conditions and actor composition.

Next, what are some specific types of policy decisions that would benefit if such a looting ABM existed? The next portion of this exercise attempts to illustrate some potential policy uses. Undoubtedly, the propensity for onlookers to become looters themselves will be one of the most important factors in determining how widespread looting will become. An ABM would allow researchers to aggregate individual-level behavior and explore the relationship between the propensity to join and the overall number of non-combatants participating in the looting at any given moment. Until such a model is built, let this following equation stand in for what this relationship might look like. L is the citywide number of looters in time period t; a is the propensity for onlookers to become looters. Let $a > 0$ for the purposes of this exercise. Again, the following equation is strictly hypothetical and does not incorporate intervention or looters running out of material to steal:

$$L_t = a\, L_{t-1}$$

Note that this equation is a geometric progression where the number of looters in any given time period is a multiple of the looters in the previous period. Figure 6-6 shows two hypothetical cases: one where there is a high propensity for looting to spread and a second where there is a lower propensity. In the high propensity case, $a = 2$ and the number of looters doubles in each time period. In the lower propensity case, $a = 1.5$ and the number of looters increases by half in each time period. Starting out initially with 100 looters, the growth after 10 time periods according to this model is shown below:

Figure 6-6. Hypothetical Number of Looters Over Time Given Different Propensities to Join in Looting



Looter growth according to a progression such as in Figure 6-6 would suggest that small changes to people's propensity become looters can have substantial impacts at the city level. One potential policy implication is that where possible, there should be an effort to change a civilian population's willingness to join in looting should it occur. Realistically, these efforts need to take place before an operation begins. This is because looting, if it happens, takes place as soon as constraints are removed. As discussed previously in Chapter 3, the U.S. invasion of Panama began on December 20, 1989 and looting in downtown Panama City began the same day. In Iraq, OIF started on March 19, 2003. U.S. troops took control of Baghdad on April 9 and looting also began the same day. In the case of Panama such advance attempts to influence potential civilian looters was not possible because the operation involved strategic surprise. Fliers or announcements telling Panamanians to continue obeying laws after the fall of their government were sure to give the Panamanian government more information than the United States was willing to give. On the other hand, Iraq offered more opportunities for U.S. forces to begin shaping the civilian response before looting began. This is because the United States had already sent a number of signals about its intentions to invade Iraq. There was also more time between the start of the operation and the fall of the regime in Iraq.

Another implication of model results such as in Figure 6-6 is that once looting has begun, intervention is likely to be most effective in the beginning time periods than after the number of looters has increased beyond a certain threshold. This is especially important where there are resources constraints, such as a limited number of troops that can be devoted to dealing with looters. In all likelihood, in future operations where looting is possible, this will mean that forces dedicated to preventing the breakdown of law and order need to be in place *before* the end of combat operations. (An alternative policy is to make a serious effort at convincing local police to continue their jobs instead of fleeing or fighting U.S. troops.) This is because troops engaged in combat will not be able to transition rapidly enough to post-conflict operations to prevent the start of widespread looting because of the timeframes involved. Conventional thinking is that troops can first conduct combat operations and then transition into post-conflict missions. However, rapid looter growth means that looting may peak before troops have completely transitioned from combat operations.[276] In both Panama and Iraq, looting began and peaked within two or three days while U.S. troops were still engaged in combat operations.

How does building an ABM improve upon using a simple equation model? For one, it does a better job of modeling social contagion such as looting. It also adds a geographical component to citywide looting that is not available in equations such as the one in Figure 6-6. If it is true that onlookers are more likely to become looters in the presence of other looters, than looting is a local contagion and needs to be modeled at this local level. This geographical aspect becomes particularly useful when attempting to evaluate intervention strategies. Knowing only the equation behind Figure 6-6 produces a limited number of policy options: reduce the propensity to join in looting, intervene early when looting starts, and perhaps reduce the number of initial looters. However, there are many more questions that an ABM would allow a researcher to ask. For instance, does the number of policing forces required to prevent or stop looting depend on the ratio of forces per population or forces per square area of the city? How sensitive is citywide looting to the geographical distribution of policing forces? Can precise information about looter activity throughout a city act as a force multiplier? When it is unknown before looting begins what areas of the city are most attractive to looters, what is the best way to deploy forces that are attempting to prevent looting? Does civilian mobility make looting more difficult to contain? If so, how effective are roadblocks and curfews at reducing looting activity?

ABM also allows policy analysts to examine the potential effect of different parameter values. For example, if looters are not deterred by the

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[276] Glenn, Paul, Helmus.

presence of U.S. forces, what are the implications? One problem that U.S. troops may have in confronting future looters is the belief that U.S. forces are reluctant to use force against civilians: many looters in both Panama and Iraq ignored U.S. forces. While this may be better for winning hearts and minds, it may be terrible for containing looting. One immediate implication is that where deterrence is weak, merely increasing the number of troops is unlikely to prevent looting from spreading. Instead, alternative policy options are needed. Restricting travel by blocking roads and enforcing curfews may offer a solution. Alternatively, modeling may show that a small force that is highly effective at dealing with looters is more effective than a force several times larger that looters feel they can safely ignore. If such is the case, it will not be enough to get troops into position quickly: there needs to be much more effort developing tactics and methods to manage a civilian population after a regime collapse. This would mean some level of training to a larger number of ground troops, such as those first into a city. Another option would be a higher level of specialized training to one particular group of soldiers or Marines who would be assigned the mission of containing any looting that does break out.

An ABM would also be an improvement over a simple equation model as in Figure 6-6 because in reality, the total number of looters over time is unlikely to be a smoothly increasing curve. There are likely to be local troughs and peaks since total looting activity will probably vary with time and location. Although equation modeling can accommodate different trends such as at nighttime versus during the day, it is difficult to use this method to assess policy prescriptions that address both dimensions. For example, it may be that looting activity diminishes as night – either because looters too need to sleep or because the lack of light interferes with identifying goods to take. If this is the case, one possible policy to further diminish nighttime looting could be to cut off power to affected areas of the city to further reduce visibility. Given their superior ability to operate under cover of night, U.S. forces might also take advantage of imposed blackouts to preposition troops in areas where looting activity is likely to resume during daylight hours. Alternatively, if darkness actually encourages looters because it leads them to believe that they are less likely to be identified and caught, the opposite tactic would be appropriate: areas of the city should be illuminated at night, possibly with additional lighting brought in by U.S. troops. Whichever case is the one borne out by further research, an ABM would be better suited to illustrating such point than an aggregate model such as the one in Figure 6-6.[277]

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[277] Glenn, Paul, Helmus. Looters in Iraq were primarily active at night.

Communication may also be introduced to agents to model the effect of rumor and information. For example, if civilians can communicate with each other, agents should learn about blue behavior from each other and react more quickly to events. The deterrence value of blue forces will then be a function of an individual agent's direct past observations as well as the past observations of agents that are near the individual or connect through networks. Rather than waiting to observe that blue agents do nothing when surrounded by looters, an individual may already assign a lower deterrence value to blue agents before it sees this inactivity because it heard from other agents about previous blue behavior. In other words, information will travel quickly on whether U.S. forces react passively or aggressively toward looters. The policy implication under these circumstances is that any observed lack of response will encourage even more looters than where there is little communication, while effective action might only need to be demonstrated to some looters and potential looters because of this "multiplier" effect.

At first glance, it seems that looting is a behavior that can be looked at independently from most other civilian behaviors and attributes. However, the layered approached discussed in this dissertation is still useful. First and foremost, the size of the civilian population is of paramount importance. Having more blue forces than civilians will produce model results that are vastly different from results from a simulated city where there are thousands of civilians for each blue soldier. Because of this sensitivity, thought needs to go into how to populate a citywide looting model. It may also seem that looting can be taken independently from simple behaviors such as congregating or running from combat. The argument for this might be that other behaviors are likely to halt during episodes of widespread looting. Yet there are some counterarguments to this position.

First, the purpose of a particular model with looting behavior may be to explore ways of preventing looting. Where this is the case, it would make sense to have civilians who exhibited background behaviors. At a minimum, this would at least allow researchers to examine if there is any effect from curfews or other methods of controlling population movement. Second, it is very realistic for looting to happen alongside combat operations. If researchers wished to examine this type of scenario in a model, it would be best to incorporate simple reactions to combat as well as looting to create a population that can respond appropriately to the surrounding environment. Population information and simple behaviors should not be ignored, but considered in any looting model.

As can be seen from this example, there are a number of potential policy options to widespread looting that can be explored using ABM. Even when a model raises more questions than it answers, there is considerable value in the exercise because it encourages thinking about a problem. The very act of trying to build a model together forces the researcher to identify gaps in the current understanding of this phenomena; to craft plausible types of interventions; and to search for policy solutions that will be robust under varying conditions. With little systematic thinking done to date on addressing looting non-combatants in urban operations, the issues raised in even this short thought exercise could constitute a rudimentary research agenda on this topic.

7. Conclusions

Non-combatants are and will continue to be an important element of the urban environment. Evaluating how U.S. military operations may affect non-combatants and how they in turn may affect U.S. military operations will be an important policy consideration in future urban operations. At the same time, the analytic tools available for exploring these issues are still being developed. There needs to be a sea change in the importance that non-combatants are given in modeling and other types of urban operations analysis. Improved representation of non-combatants in models and simulations would complement the current suite of analytic tools that the U.S. military can use to better prepare for urban operations. Chapter 7 provides some final comments about the layered approach that this dissertation recommends for incorporating civilians into military models. It also discusses policy recommendations, and the broader policy implications from improving modeling and simulation of non-combatants and from improving understanding of non-combatant behavior in general. It concludes with areas for future work.

Layered Framework for Modeling Non-combatants

This dissertation has proposed a layered framework for incorporating non-combatant behavior into military models and simulations. The first layer consists of population size, population density, and other demographic characteristics. As discussed extensively in previous chapters and as shown in an example using the leadership strikes during OIF, basic information on population density enables policy makers to evaluate certain courses of action. These include airstrikes in populated areas, weapons choice, targeting procedures, weapons development, force structure requirements, and other planning choices. Simple calculations with population information often offer good first approximations for many metrics of interest, such as civilian casualties or the number of peacekeeping troops that are necessary for an operation. They also offer a baseline for other analyses that contain active non-combatants. The need to have a correctly sized urban population in these types of analyses should be clear, since a different population size will yield different results model or analysis results.

The next layer in the proposed framework is simple behaviors: background physical movement and simple reactions to combat. Incorporating these behaviors into a model go a long way towards creating a simulated civilian population with realistic individual-lvel behaviors. It also expands the range of policies that may then be examined in analytic tools. It now becomes possible to consider ways to encourage or discourage population movement; the effect of an active non-combatant population on U.S. troop mobility; and the effect of moving civilians on the fog of war. Some specific policies that may now be evaluated include curfews, roadblocks, rules of engagement, tactical surprise, and different sensor technologies. It should also be possible to evaluate U.S. and enemy combatant tactics in urban areas in ways that it cannot be done in models with static or purely scripted non-combatant actors. If civilians are a vital part of the urban environment, populating models to the correct scale and introducing simple behaviors together open up new areas in urban operations analysis.

Complex behaviors are the most advanced, the most changeable, the most situation-specific, and some of the most dangerous civilian behaviors for U.S. forces. These behaviors further expand the scope of policies and options that decision makers can use models and simulations to assess. In addition to the policy alternatives that can be examined when simple behaviors are introduced, it is now possible to consider advanced U.S. and enemy combatant tactics. Population and simple behaviors tend to describe generic non-combatant populations. In comparison, the complex civilian behaviors described in Chapter 6 are less frequent, harder to predict, and far more variable. Their addition allows researchers to expand the range of scenarios they can create in a simulation and to produce situations that are more challenging, more hostile, unpredictable, and unique. This is especially true when civilian agents are able to learn, adapt, and communicate.

It is vital to make the point that the middle and top layer of the proposed framework – simple and complex behaviors – cannot stand without the bottom layer of populating models. This point bears repeating and if the reader remembers one argument in this dissertation, this should be the one. Introducing simple *or* complex behaviors without taking the correct population densities into account has shortcomings. It is not analytically sound to recreate detailed behaviors but give scant thought to how a model should be populated with civilians. For many policy questions, a static model with the correct population size may be more useful than an urban operations model that has complicated civilian behaviors but more combatants than non-combatants. This is because the former may be truer to capturing information relevant to a policy problem than the latter. There is much more to the urban environment than buildings, and the current emphasis on modeling physical terrain could be missing the forest for the trees there this isn't equal attention to the non-combatant element.

Neither should researchers assume that complex behaviors can be taken separately from simple ones. As previously discussed, there are situations when combat can bring about a momentary halt to background behaviors. Yet actions such as throwing rocks at U.S. forces do not exist in a vacuum from other civilians running from combat or attempting to travel. Many plausible behavioral pathways also include movement back and forth between complex and simple behavior, strengthening the case to include both together. Focusing on the complex behaviors can also be analytically misleading, because it may incorrectly set these as default non-combatant behaviors in a model. Because of their more sporadic nature, it is better to set the simple behaviors as the base behavior and ask what happens when particular combinations of complex behavior arise. Because these complex behaviors *are* harder to predict, an approach to examining these behaviors in models and simulations should be done in a way to take this uncertainty into account.

Policy Implications

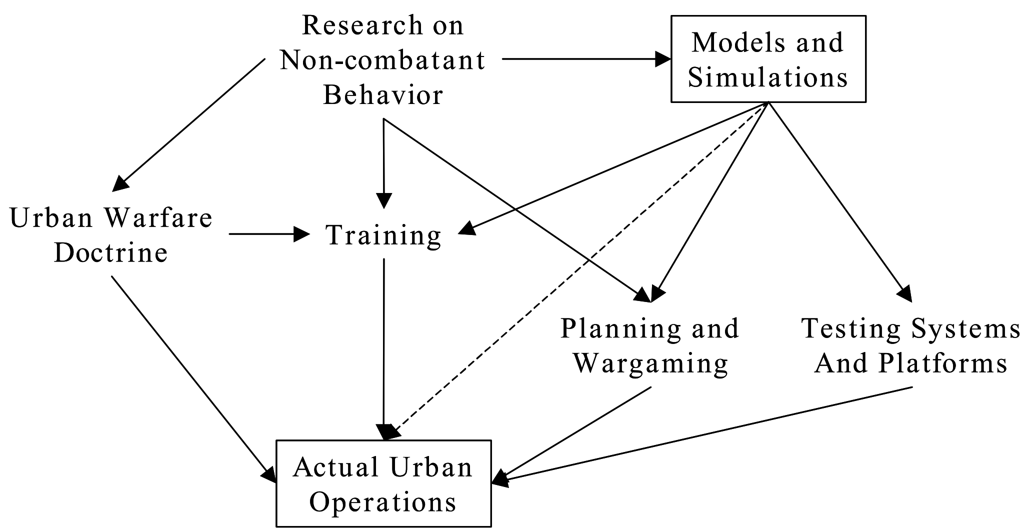
Modeling and simulations have their uses and limitations; they can never fully substitute for the reality that they attempt to represent, especially for phenomena as complicated as warfare. They suffer from limitations in scope, data, and imagination. Assumptions and weaknesses in a model are not always easily evident, and may result in some misunderstanding or misapplying model results. It is relatively easy to be seduced by models – to think that they capture reality better than should be able to, given their assumptions. Building large-scale models and simulations often also absorbs resources that could have been spent on other useful forms of analysis, while producing output that not all find useful or even understandable. There is also the danger for model developers to fall in love with their model: building the model becomes the goal in and of itself, rather than seeking to shed light on specific policy problems.

However, models and simulations do serve a purpose. Some form of analysis usually needs to be done between actual urban operations. Models can often offer advantages not available in other tools, including the chance to simulate a much wider range of conditions that would be possible in reviews of past operations or physically recreations of the urban environment. Combining improved models and simulations of urban warfare with other research, training, and planning methods should enhance overall understanding and preparation. Using multiple alternative analytic approaches should also help mitigate many of the potential pitfalls of using models, such as believing too much in an individual model or failing to understand the extent of a model's limitations. A commitment to approaching a problem from many analytic angles could even help models and simulations from drawing a disproportionate share of resources as well, since it implies that efforts are made to advance analysis along different avenues. In short, the best defense against the misuse of models seems to be to prevent modeling in a vacuum, and to avail modelers to other sources of research and analysis.

Another defense, one naturally occurring in the Project Albert work, is to encourage the development of many models whose results can be compared. Different models will have different strengths, and differences or contradictions in their results should help reduce model misuse and encourage more rigorous analysis overall. Creating competing models is the most productive when model creators come from diverse backgrounds, emphasize different issues, and work without too much regard for what others have found. This particular defense will be less successful if research converges or if researchers begin to standardize which models they use. This has begun to happen somewhat within Project Albert, and it should be noted that the presence of many models is analytically healthy. However, developing multiple models is likely to be impractical when simulations need to be very large and very complex, since not enough resources are likely to be available to develop many alternative models.

As part of a larger research agenda on non-combatants in urban operations, improved urban models and simulations do have the potential to improve policy on a number of levels. Again, used in conjunction with other types of analysis and compared with competing models, they do have the potential to be useful. Models and simulations directly feed into the conduct of actual military operations for certain classes of problems, such as those that require optimization or scheduling. For problems such as managing and shaping the urban environment, their influence is more indirect but still potentially important. Figure 7-1 illustrates one way to conceptualize the way that modeling and simulations fit in relative to the conduct of actual urban operations:

Figure 7-1. Impact of Models and Simulation on Actual Urban Operations



As Figure 7-1 shows, there are many ways that bringing realistic non-combatant behavior into urban combat models and simulations can ultimately affect the conduct of future urban operations. Training is one key area where this could have a substantial impact in the future. While it cannot completely replace physical instruction and live training, simulation is sometimes used as a training tool to reduce costs and physical risks. Currently, there are a number of advanced models and simulations being considered for urban operations training, such as OneSAF, Full Spectrum Command, and JCATS.[278] Incorporating an agent-based non-combatant population into a constructive model such as JCATS would expand the scope of that particular model in a very productive way. Quite obviously, having a high density of realistic non-combatants would create a simulation that more realistically reflects an urban environment. For example, an advanced simulation used to teach small unit-level tactics could better recreate the clutter and confusion that a city presents by including large numbers of civilians reacting in multiple different ways.

Aside from teaching or reinforcing certain combat skills, models and simulations have the ability to graphically demonstrate the types of past urban environments that U.S. forces have encountered. Visualization is a powerful

[278] E-mail correspondence with Randall Steeb at the RAND Corporation on MOUT modeling, December 1, 2004, Santa Monica, CA.

teaching tool, and using models and simulations to present a library of past urban experiences would have considerable training value. Using models to illustrate historical knowledge would draw information in case studies, lessons learned, and other sources to create a unifying training tool. In past U.S. urban operations, the nature of the surrounding population has been a large driver in shaping the character of the urban environment and determining the range of appropriate actions for U.S. troops. Capturing some of these civilian characteristics will be vital in simulating urban environments that are realistic enough to use in training.

One might create training modules with hostile crowds in the Balkans, looters in Panama, traffic jams in Haiti, swarming civilians in Somalia, or civilians being used as involuntary human shields in Iraq. The lessons that a trainee draws from each scenario should be based on the actual dynamics of that event. Because there can be considerable interaction between enemy combatants and civilians, such recreations of past scenarios should include the enemy tactics and how the enemy used or benefited from the surrounding population in each particular instance. It should allow a trainee to understand the range of urban situations that has occurred in the past and the different (or common) skills and tactics that were required across each type of event. It would bring home the range of scenarios one might face, from rock-throwing crowds to cheering ones, violent looters to traffic jams, and voluntary human shields to civilians accidentally driving towards U.S. forces. Had such a tool been available to U.S. troops before OIF, looting in Iraq would not have entirely surprised them because they would have encountered it in simulations that include elements from cases such as Operation Just Cause. And if U.S. troops in OIF had responded to early looting based on their understanding of looting in Panama, there is the very real possibility that it could have altered the course of events. In addition to recreating past events, models and simulations can create entirely new scenarios to present trainees with unexpected situations. Variation in the complex behaviors, in particular, can go a long ways toward generating unknown but challenging urban conditions.

Having artificial civilians at the correct density and reflecting realistic behavior is also important when models and simulations are used to test weapons and platforms, particularly those that are in development. There are ongoing efforts within the defense community to improve models and simulations of the urban environment precisely in order to test technologies that may be helpful in urban operations. Such efforts include further development of the Joint Semi-Automated Forces (JSAF) model – a variation of OneSAF – and other simulations.[279] Again, using a non-combatant ABM overlay to salvage constructive models such as JCATS or Janus would also extend these their use and provide decision makers with usable models sooner. Urban models and simulations that can give estimates for civilian casualties that are on the correct order of magnitude should be helpful in evaluating the ability of different weapons, munitions, or sensors to minimize civilian injuries. Populating models with more realistic population densities should also provide evaluators with a simulated environment that better reflects the challenges posed by urban areas. As discussed earlier, effectively modeling urban civilians would assist in evaluating non-lethal weapons that are being developed. Because actually deploying non-lethal weapons on live human beings is restricted due to ethnical and legal issues, simulation may be the only real tool for exploring issues related to their use among urban populations. Incorporating demographic information that reflects the high percentage of young children in developing countries could uncover the disproportionate harm that such weapons might do to the most vulnerable civilians.

Also as noted in the example at the end of Chapter 5, the Army's FCS program is a network-centric suite of systems that are meant to be effective across the full spectrum of operations. Simulating the FCS in urban combat currently offers the method to evaluate how the systems might fare in cities. In addition to issues such as weapons choice discussed in the example, simulations may prove to be important for this program at conceptually more advanced levels. Compared to previous weapons systems, the configuration of an FCS force deployed in the field will vary substantially depending on mission and conditions. The ability to simulate different urban conditions and experiment with results should help the Army gain a better understanding of how to equip and organize its FCS forces in future operations. Non-combatant models could help the Army decide on the mix and size of an FCS task force to send on a mission. At a minimum, they should raise awareness that the optimal organization will change depending on the civilian component of an urban area and hopefully better inform long-term decisions about FCS development and deployment.

Adding more realistic non-combatants to urban models and simulations will also be helpful is in planning, wargaming, and other types of experimentation. Clearly, a simulated urban environment offers greater room for pure experimentation than one that is physically constructed and populated with live actors. This is because simulated environments can easily offer a

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[279] Ceranowicz and Torpey, pp. 1-2.

greater range of conditions, scenarios, a larger scale, and even a greater number of runs due to cost effectiveness. Although live environments offer significant advantages, their use is limited by resource constraints and the need to limit actual physical risk to participants. Hence it is possible to set up several blocks with enemy combatants and non-combatants, but impossible for live exercises to frequently involve truly city-sized areas and millions of non-combatants. It is possible to train on a few different scenarios involving hostile crowds but impossible to experiment with swarming or looting civilians. At the same time, there are precisely the dangerous situations that U.S. forces need to prepare for the most.

Experimentation and wargaming can involve questions at the strategic, operational, and tactical levels. Urban simulations could be used to explore tactics and strategies that enemy combatants might employ to use the urban population to their advantage. Although it is impossible to anticipate the full universe of potential future events, using urban models as laboratories could inspire ideas. Simulations could also be used to generate hypothesis on managing civilians under different circumstances. In particular, using agent-based models would depict civilian behavior as a complex adaptive system that has non-linear effects, such as escalated looting. ABMs with large non-combatant populations could encourage thinking about early intervention or managing early conditions because of the way CAS events can become more than the sum of its parts.

The best-case scenario is that experimenting with non-combatants in models and simulations will give rise to new tactics and strategies on how to deal with non-combatants and enemy combatants who make use of the surrounding population. The goal would be to improve analysis on what actions can reduce civilian casualties and allow U.S. forces to accomplish their objectives in the midst of a civilian population. How does dispersing, concentrating, or otherwise controlling civilian movement potentially affect the outcome of a mission? How effective is separating enemy combatants from non-combatants? What is the level of non-combatant casualties using one tactic versus another one, given clutter and certain errors rates in identification? How does civilian affiliation with one side of a conflict or another change events, intelligence, or access to information? There is no shortage of questions or problems that need examination.

As it has been stated often, models (and even live exercises) are not reality: there is no guarantee that simulation results will be indicative of actual results for something as “fuzzy” as non-combatant behavior. Because of this, it is best to accept model output with a grain of salt and to see if other forms of research can collaborate such results. For example, simulation of large civilian populations may show that use of force against early looters prevents the outbreak of citywide looting. If other known police or peacekeeping research is consistent with such findings, such tactics may be plausibly considered in future urban operations. It is easier if a simulation is used to extend something that is already known. For example, previous experience may strongly indicate that curfews decrease certain types of insurgent activity. Using a model to display what happens at a citywide level with different curfew strategies would give results that are more certain, since it was based on dynamics that were already known to be true. Thus, in the area of experimentation, models can be used to suggest brand-new tactics and to show the results of implementing accepted tactics in different ways.

Planning is another major area that can be improved by urban models and simulations with better depiction of non-combatants. Improved tools help planners in two ways: by addressing specific planning problems, and by forcing clearer thinking about assumptions, risk, and uncertainty. Models that have good information about civilian populations could help answer questions about force sizing and force requirements for a variety of support, stability, humanitarian, peacekeeping, and other operations. In many of these cases the size and disposition of the civilian population drive force requirements. Chapter 4 offered an example of a simple back-of-the envelope calculation for the size of the force that was potentially required for post-conflict operations in Iraq under different conditions. Even such rudimentary "models" offer useful guidelines for future situations based on past experience.

Additionally, improved models and simulations can advance planning by forcing decision makers to clearly consider their assumptions. For example, U.S. policy makers went into OIF preparing for humanitarian disaster but not preparing for looting or an insurgency. If there had been tools that ran many more scenarios, U.S. forces might have been better prepared to meet some of the challenges that they did. At a minimum, explicitly raising the possibility of other scenarios could make clear which ones U.S. decision makers are choosing not to consider. But laying out the range of non-combatant behaviors, such tools might also encourage thinking about how behavior can change dynamically over time and how U.S. forces might need to adapt. Future urban operations will demand a great deal of interaction with the surrounding civilian environment, and more information about civilians is sure to improve higher-level planning decisions.

This dissertation recommends that planners begin to compare their expectations for future operations against the full spectrum of non-combatant behaviors and interaction between non-combatants and combatants. Just as the Army must first be familiar with the full spectrum of warfare to be able to plan for it, those who are looking to be prepared for operations across the full spectrum of urban operations must first know the range of a vital dimension of the urban environment – civilians. Such a shift in thinking is analogous to the trend away from threat-based planning and toward capabilities-based planning. In threat-based planning, military planning is done around a specific threat that a specific adversary is thought to pose. In capabilities-based planning, planning is based on providing U.S. forces with the capabilities to meet a broad range of scenarios that may occur. There is a built-in attempt to deal with uncertainty in capabilities-based planning because it attempts to prepare U.S. forces for a number of situations that may happen. (This is in contrast to threat-based planning, where only one situation is anticipated.) The same now needs to be done for urban operations, and such an effort should begin with understanding the range of scenarios in the urban arena.

Policy Recommendations

This dissertation has a number of recommendations. First, model developers should use ABM to incorporate non-combatants into existing, accredited constructive models. As discussed earlier, this would salvage the enormous investment that has been made in these simulations and would extend their use beyond force-on-force scenarios to urban operations scenarios as well.

Second, Project Albert agent-based models should incorporate the recommendations that this dissertation has given for populating ABMs with more realistic non-combatants. The natural fit between non-combatant behavior and ABM makes it logical to do so. As has been discussed, there has been considerable work using ABM to model social behavior in areas that would be relevant to urban populations. Project Albert researchers are already using ABMs to experiment creatively with basic tenets of warfare as well as tactical questions in specific combat and MOOTW scenarios. Project Albert research has progressed to a level where there has already been considerable thought given to complexity, uncertainty, and the uses and limitations of ABMs to further military knowledge. Intensive experimentation with urban populations in ABMs is a natural and timely evolution of its research agenda, particularly given the current policy relevance of urban operations for Project Albert's primary sponsor – the U.S. Marine Corps.

Third, information on past non-combatant behavior reviewed in this dissertation should be incorporated into current efforts to develop the next generation of urban combat simulations that will be used for asking tactical and technological questions about urban operations. As discussed in Chapter 1, Urban Resolve is one such attempt to advance urban models in order to arrive at new approaches to urban combat. As argued earlier, Urban Resolve does not go far enough in populating its terrain with non-combatants to approach the population densities actually seen in past urban operations.[280] Including the simple reactions to combat discussed in Chapter 5 and the complex behaviors discussed in Chapter 6 would greatly expand on the repertoire of civilian reactions in JSAF beyond daily travel and traffic patterns. These current limitations on the non-combatant component of the Urban Resolve project will result in considerable resources being spent to develop a tool that is not flexible enough to answer many pressing questions about urban operations. Because civilians are an influential but unpredictable force in urban operations, it would be ideal to create them as such in future urban combat models. To do otherwise would limit the scope of the experimentation that can be done with new tools and would therefore undercut some of the rationale for developing these new tools.

Fourth, non-combatant behavior should be more extensively incorporated into the research and development of technology solutions for urban combat needs. For example, Joint Publication 3-06, *Joint Urban Operations*, uses USECT (Understand, Shape, Engage, Consolidate, and Transition) as a way to describe the nature of urban undertakings.[281] It is aimed at improving the way different types of information at all levels of an urban operation are gathered, processed, disseminated, and displayed. One product of this research effort is Optipath, a Canadian project aimed at better navigation during urban operations. Optipath is envisioned to improve tactics, intelligence collection, mission planning, command and control, logistics, and coordination between land vehicles. It would communicate with a larger urban operations software architecture and provide optimal navigation through a city. In an attempt to be useful in a dynamic urban environment, Optipath explicitly takes into account other agents on a road network (including non-combatants), their interaction with terrain, and their potential impact on friendly forces.[282] In short, Optiopath's purpose is to improve the ability of vehicles to better navigate a city

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[280] Certanowicz and Torpey, pp. 3, 5. 25,000 pedestrians and 75,000 vehicles do not approach the level of clutter that one may expect to see in a city with 1.8 million buildings.

[281] United States Department of Defense, Joint Publication 3-06, *Doctrine for Joint Urban Operations* (Washington, D.C.: Joint Chiefs of Staff, September 16, 2002), pp. viii, II-13-4.

[282] Luc Pigeon and Yves van Chestein, "Navigation in Extreme Environments: the Optipath Capability," (Val-Bélair, Québec: Defence R&D Canada, 2004), pp. 1, 4-6.

during operations, given other activity on the road network and other real-time data on conditions. Clearly, some concept of civilian behavior and movement and their implications for forces operating in a city would be an important part of Optipath's ability to deal with a dynamic environment. The research presented in this dissertation would be a start to creating an Optipath prototype that is intelligent about guiding vehicles through a city with crowds, civilian traffic, riots, and other such civilian activity.

A fifth recommendation that immediately comes from this dissertation is to better capture and more extensively analyze current lessons that are being learned about non-combatant behavior and its implications for urban operations. As much information as possible should be recorded on the effectiveness, advantages, disadvantages, and other attributes of tactics and measures used to deal with civilians. Such qualitative research and analysis serves to balance research based primarily on models and simulations, and helps to act as a defense against some misuse of models. There should be considerable attention given to writing down what is currently being learned about controlling civilian populations, mitigating advantages they offer to enemy combatants, and improving their disposition towards U.S. forces. This is something that model developers may wish to be involved with, given the payoffs from having this information available for modeling non-combatants. Investing in a central repository for non-combatant information is recommended. Figure 7-1 shows how non-combatant research in general eventually affects the conduct of urban operations on the ground.

Sixth, there should be further investment in modeling and simulation-based urban operations training. Specifically, models and simulations should be used to train U.S. forces in the lessons learned from dealing with non-combatants in past urban operations. Modeling and simulation can be very good at demonstrating what is already known from past urban experiences and creating entirely new situations. Using simulation to create a virtual training library of the non-combatant component of past urban operations would be an invaluable tool for passing on institutional memory to new soldiers and Marines. Although this type of application is very advanced and further off in the future, it would have considerable value in preparing U.S. forces for future urban operations.

Seventh, there are a number of gaps in knowledge even within the rudimentary framework presented in this dissertation. The discussion has dealt with relatively few behaviors at each level of the suggested behavioral layer. Additional research could expand this list to cover others types of salient demographic information, as well as other simple and complex behaviors that show themselves to be important. To better understand non-combatant behavior, additional work is also needed on behavioral pathways, crowd behavior, and other topics that have not yet been extensively researched. There should also be work done on non-combatant behavior that was not covered by the three case studies, such as refugee behavior, ethnic cleansing, and other violent civilian behavior that might be of relevance in urban operations. Depending on the case, it may even be useful to examine civilian behavior in non-U.S. operations.

Lastly, there are other ways to approach the problem of understanding civilian behavior during times of war. Developing conceptual frameworks that are different from the one offered in this dissertation and exploring additional methods of representing them in simulations and analysis should be encouraged. This is a topic that merits considerable attention and it requires additional interested researchers to build a more solid base of knowledge. There is no shortage of questions to ask about non-combatants in urban operations, and there is a definite need to include them in the analytic tools that policy makers depend upon to shape decisions

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